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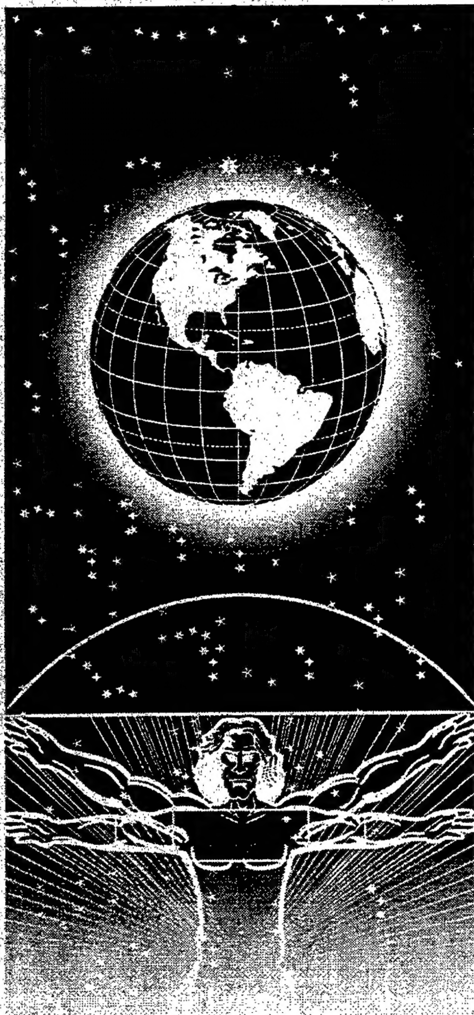

UNITED STATES AIR FORCE
ARMSTRONG LABORATORY

Desktop Corrosion Control Study for Thule Air Base, Greenland

David M. Mihalick, Second Lieutenant, USAF, BSC

May 1997

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The Water Quality Branch of the Armstrong Laboratory, Occupational and Environmental Health Directorate, Bioenvironmental Engineering Division performed a Desktop Corrosion Control Study for Thule Air Base, Greenland following Environmental Protection Agency (EPA) Guidance. Specifically, the study evaluates the validity of recommendations made in a previous desktop study accomplished at Thule. Using the EPA seven step approach for completing desktop evaluations, and the available information, the recommended treatment option for Thule is silicate inhibitors.

Additionally, the report makes recommendations to the base regarding data information that needs to be collected and analyzed before any final decisions are made. First the base must define pH over the entire distribution system. Second, the base needs to research the reported application of polyphosphates over a 35 year period and assess the impact. Third, the base should perform identification oriented sampling to isolate the source of lead in first draw tap samples. Fourth, the base should compile all available data relating to lead and copper corrosion control into one consistent database. Each of these actions will allow an engineer to make better recommendations for corrosion control.

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We would like to take this opportunity to thank Capt Jay Vietas, Chief of the Operational Support Element of the Bioenvironmental Engineering Flight at Peterson AFB, Colorado and TSgt Kelly Brown of the 12 SWS/MAS-SGB at Thule AB, Greenland for providing information used in the preparation of this report.

DESKTOP CORROSION CONTROL STUDY FOR THULE AIR BASE, GREENLAND

INTRODUCTION

Thule Air Base (AB) is located in northwestern Greenland. The base is approximately 950 miles south of the North Pole and 800 miles north of the Arctic Circle. Thule is home to the 12th Space Warning Squadron (12 SWS). The mission at Thule is to provide warning of ballistic missile raids against the United States and Canada to the unified and specified commands.

The scope of this project was to complete a desktop corrosion control study for Thule AB to determine, if possible, the cause of high lead and copper levels in first draw tap sampling under the Lead and Copper Rule (LCR). In April 1995, Pacific Environmental Services (PES) completed a desktop corrosion control study for Thule Air Base (Appendix G is a complete copy of the PES report). The report was completed under Contract No. F33615-89-D-4000, Delivery Order No. 0041. The report recommends addition of silicate inhibitors as the optimal corrosion control treatment for Thule. The report steps through the Environmental Protection Agency (EPA) seven step approach for completing desktop evaluations. The seven steps to follow, as presented in the LCR Guidance Manual are listed below.

1. Define existing conditions
2. Monitor Lead and Copper at points of entry and determine source water treatment needs
3. Define constraints
4. Identify corrosion control priorities
5. Eliminate unsuitable approaches
6. Evaluate viable alternatives
7. Evaluate each alternative based on four selection criteria
    a. performance
    b. feasibility
    c. reliability
    d. cost

This desktop study was requested by Capt Jay Vietas, who is Chief of the Operational Support Element of the Bioenvironmental Engineering Flight at Peterson AFB, Colorado. Because Thule is part of the USAF Space Command, Peterson AFB is responsible for Bioenvironmental Engineering functions at the base. Capt Vietas tasked Armstrong Laboratory's Occupational Health Directorate, Bioenvironmental Engineering Division, Water Quality Branch (AL/OEBW) with critically reviewing the PES report and identifying other possible solutions for corrosion control.

All data used in completing this study was gathered by personnel at Thule Air Base. TSgt Kelly Brown was the main point of contact at the base and gathered most of the information. Lt David Mihalick reviewed lead and copper sampling results and water distribution system information. Appendix A is a summary of the lead and copper sampling results since July 1993. Supplemental water distribution system and water quality information was obtained from the April 1995 PES report. Additional background information was obtained from the United States Environmental Protection Agency (EPA) and from The New England Water Works Association (NEWWA). The table below provides a list of contacts:

Table 1. List Of Contacts

NAME	ORGANIZATION	PHONE NUMBER
Capt Jay Vietas	BEE (Peterson AFB)	DSN 834-7721
TSgt Kelly Brown	12 SWS/MAS-SGB (Thule AB)	DSN 268-3840 x2782
Karen Eager	NEWWA	(603) 298-7061
Ellie Kwong	USEPA Region 1	(617) 565-3604
2Lt David Mihalick	AL/OEBW (Brooks AFB)	DSN 240-4938

The remainder of this technical report a critical review of the desktop study completed by PES, which recommends the addition of sodium silicate as optimal corrosion control treatment. The three corrosion control techniques generally considered during desktop evaluations are pH/alkalinity adjustment, calcium hardness adjustment, and introduction of corrosion inhibitors (phosphates or silicates). The reasons that PES rejected pH adjustment, calcium carbonate precipitation, and phosphate inhibitors will be investigated. The reasons that PES chose silicate inhibitors will be critically evaluated. Additionally, the report will evaluate possible infrastructure changes that might help solve lead and copper problems.

CORROSION CONTROL BACKGROUND

Adjusting the pH or alkalinity of the water in the distribution system is known as a passivation mechanism. The goal of passivation is to form metal complexes at the pipe surface that are less soluble than complexes that would be formed otherwise. The complexes interact with the water at the pipe boundary and keep lead in the pipe. The intent of pH/alkalinity adjustment is "to induce the formation of less soluble compounds with the targeted pipe material" (LCR 1992). Introduction of corrosion inhibitors is another passivation technique, employing the same general principle as pH/alkalinity adjustment. Commonly used inhibitors are phosphates and silicates.

Calcium hardness adjustment is known as a precipitation mechanism because the intent is to precipitate calcium carbonate out of the water in hopes of forming a protective layer on the pipes' interior surface. Ideally, the protective layer is thin and uniform so as not to restrict flow. Several indices exist which are intended to help predict the likelihood of precipitating calcium carbonate. The EPA recommends using the Calcium Carbonate Precipitation Potential (CCPP) in The Lead and Copper Rule Guidance Manual: Volume II. Another value commonly used in evaluating the corrosivity of water is the Langelier Index. It is very difficult to accurately predict

the formation of a calcium carbonate layer throughout the distribution system. Calcium must be available at all points to ensure the entire system is covered. This is analogous to the need to maintain a chlorine residual throughout the distribution system. In order for disinfection to be effective, free chlorine must be present at all points in the system. Likewise, in order to precipitate an effective layer of calcium carbonate, calcium must be present throughout the distribution system. Finally, it is difficult to ensure that the layer formed is uniform. If the calcium carbonate begins to build up in spots, the flow will become restricted and pressure problems may result.

The most appropriate corrosion control mechanism varies with water quality parameters and the distribution system characteristics. The seven step approach guides a water system toward the optimal treatment technique.

EPA SEVEN STEP APPROACH FOR DESKTOP EVALUATIONS

Define Existing Conditions

The important water quality parameters to monitor in evaluating lead and copper corrosion problems include lead, copper, iron, manganese, magnesium, sodium, calcium, pH, alkalinity, temperature, conductivity, orthophosphate, and silicate. The following table summarizes water quality information provided for preparation of this report.

Table 2. Water Quality Parameters

Parameter	Location	Units	Value
Lead	Lake Crescent	mg/L	< 0.001
Copper	Lake Crescent	mg/L	< 0.02
Iron	Potable water	mg/L	1.2
Manganese	Potable water	mg/L	0.068
Magnesium	Potable water	mg/L	7.7
Sodium	Potable water	mg/L	4.8
Calcium	Potable water	mg/L	11
pH	Lake Crescent	-----	6.6
Alkalinity	Lake Crescent	mg/L	20
Temperature	Lake Crescent	degree C	2
Conductivity	not provided	-----	-----
Hardness	Lake Crescent	mg/L	40
Orthophosphate	Potable water	mg/L	< 0.10
Silica	Potable water	mg/L	1.1

Thule AB gets water from Lake Crescent, located approximately 10 miles from the base. The samples reported in Table 2 taken from the potable water supply represent the most current samples provided. Values presented in Table 2 do not necessarily reflect values measured from a single sample. The value of each parameter is the most current value provided by the base.

Water is taken from Lake Crescent and piped to the main base through a 8 inch high density polyethylene (HDPE) plastic pipe. Exterior water pipes at Thule include both steel and HDPE pipes. The 100, 500, and 700 areas have steel pipes. The rest of the base has 2 to 8 inch HDPE exterior pipes. Interior piping is copper with lead soldered joints. The copper piping in the buildings was installed by the Army Corps of Engineers in 1956 and 1957. The system also contains copper and chrome plated brass faucets, goosenecks, elbows, and valves. Each of these fixtures is potentially a significant source of lead in the potable water.

In addition to the main base, there is also a separate water distribution system at the J-Site, or Ballistic Missile Early Warning System (BMEWS). This system consists of new steel pipe. Thule is currently adding hexameta phosphate to this system in an effort to establish a passivating film on the interior surface of the pipe. They plan to add the phosphate for three years. A similar experiment was attempted over 35 years ago with the main base water distribution system. At that time, the base added polyphosphates to the water in an effort to establish a passivating film. However, they never monitored the effectiveness of the inhibitor and continued to add it until 1991. In 1991 they quit adding the inhibitor to the main base distribution system. There were no system evaluations to determine whether or not the 35 years of phosphate addition had any impact on the distribution system.

Source Water Treatment

As presented in Table 2, there is no detectable amount of lead or copper in the water from Lake Crescent (Appendix A contains complete lead and copper sampling results). The water has a temperature of 2 degrees Celsius. The pH of the water is approximately 6.6 and the alkalinity is only 20 mg/L as $CaCO_3$. The water is also a low hardness water at only 40 mg/L as $CaCO_3$.

As stated in the PES report, water with the characteristics of Lake Crescent is very corrosive to galvanized iron, black iron, and copper piping. It can also be corrosive to lead solder.

Define Constraints

Realistic constraint definition is vital to a successful corrosion control program. A solution might appear effective when evaluated for its ability to eliminate lead and copper in first draw tap water; however, when evaluated considering its effect on other water quality goals, the distribution system, or wastewater considerations, the solution might prove ineffective. Tables 3-3a and 3-3b of the LCR Guidance Manual address possible constraints (Appendix B).

Table 3-3a indicates that pH adjustment before disinfection will reduce chlorine effectiveness. The minimum CT (concentration multiplied by contact time) value must be maintained after the pH is elevated. This may require increasing the free chlorine residual or the contact time. Otherwise, there is an increased potential for violation of the Coliform Rule with pH adjustment. If sodium based chemicals are used to alter pH/alkalinity, the effect on total sodium in the finished water should also be considered. Currently, the water contains sodium at 4.8 mg /L. This is safely below the EPA suggested maximum concentration of 20 mg/L (De Zuane, 1990).

The optimal place for pH adjustment is somewhere after chlorination, as close to entry into the distribution system as conditions permit. If pH adjustment were attempted, then it would likely occur in Building 1400, after the water has passed through the 10 miles of HDPE pipe from Lake Crescent to the base.

Additionally, if high levels of dissolved metals exist, raising the pH could cause the metals to precipitate. If the metals precipitate, the particulates can cause scaling of the plumbing, clogging of heat exchangers, or unacceptably high turbidity. This problem may effect users with specific water quality needs, such as health care facilities. If the water contains high levels of calcium or dissolved inorganic carbon (DIC), unintentional precipitation of calcium carbonate may result. DIC in excess of 15 mg/L can lead to an increase in lead and copper by forming soluble metal complexes (JNEWWA 1995). Some metals concentrations are reported in Table 2 above. The major cause for concern with metals is the reported level of iron. Iron should not exceed 0.30 mg/L in finished water (JNEWWA 1995). The reported level at Thule is 1.2 mg/L. Iron levels as high as 2.1 mg/L and as low as 0.16 mg/L are reported in the distribution system. It is likely that the reported red/rusty water complaints are a result of the high levels of iron and manganese. High levels of iron can also cause laundry stains (De Zuane, 1990). In addition to the red water complaints, the system has also had complaints about taste and odor. Some filamentous organisms prey in iron and can cause taste and odor problems.

Table 3-3b indicates that phosphate based inhibitors can have detrimental effects on the water system. First, phosphate based inhibitors tend to deplete chlorine residuals throughout the distribution system. This affects the disinfection capacity. If this is a problem, additional chlorine can be added to satisfy the increased chlorine demand created by introduction of the phosphates. Second, some systems have experienced an increase in microbial growth after introduction of phosphate based inhibitors, resulting in unwanted biofilms. However, the EPA also reports in the LCR Guidance Manual that there is no direct evidence "available indicating that the introduction of phosphate based corrosion inhibitors would foster or encourage the growth of bacteria in the distribution system" (1992). This statement and Table 3-3b, which both come form the same document, are contradictory. Most sources indicate no direct link between the addition of phosphate inhibitors and microbial growth in the distribution system. Medlar and Kim state that "small systems should not rule out phosphate inhibitors unless biological regrowth has been a serious problem" (1994). If corrosion byproducts are released after the inhibitors are introduced, coliforms may be detected with greater frequency. It appears that corrosion byproducts, and not the inhibitor, may lead to increased microbial growth.

Finally, some inhibitors, like zinc orthophosphate, must be carefully considered because of the contaminants they can add to the wastewater. Use of zinc orthophosphate can increase zinc concentrations in wastewater treatment plant (WWTP) effluent or in processed sludge. Any final decisions must consider limitations in the WWTP NPDES permit or other applicable regulations.

In addition to the above process constraints, a myriad of functional constraints exist. Addition of any chemicals to the system must be carefully controlled. If the chemical additions are manual, the operators will need proper training. If the chemicals are added mechanically, equipment must be purchased and monitored. Operators will need training. Also, users with

specific water needs, such as health care facilities or heating plants, must be notified of any changes in the treatment process. Finally, inhibitors may cause physical water quality problems. The result can be red water, dirty water, color, and sediment complaints because of the action of the inhibitor on existing corrosion byproducts. Although each corrosion control technique has certain drawbacks and limitations, they each offer benefits depending on the specific water quality.

Identify Corrosion Control Priorities

There are no reported problems with lead or copper levels in Lake Crescent, therefore, source water treatment is not a priority. During the initial LCR sampling, both lead and copper exceeded the established action levels. However, during subsequent sampling copper levels were consistently below the action level, while lead levels consistently exceed the action level. Consequently, the priority at Thule is reduction of lead in first draw tap samples.

Eliminate Unsuitable Approaches

The PES report eliminates Calcium Carbonate precipitation as an approach for corrosion control at Thule. This elimination is plausible. Currently, the CCPP of the water entering the distribution system is -35.18 (RTW, 1996). In order to bring the CCPP into the 4-10 mg/L range recommended by the EPA for precipitation of calcium carbonate, 40 mg/L of calcium carbonate would have to be added (RTW, 1996). This addition would significantly increase the hardness of the water. The Langelier Index calculated by the RTW model is -3.30 (See Appendix C for complete model results). The Langelier Index should be greater than zero for calcium carbonate precipitation to occur.

The EPA reports that water with low alkalinity, pH, and calcium content usually requires excessive treatment to generate conditions necessary to precipitate a protective calcium carbonate layer (LCR Guidance Manual, 1992). Furthermore, the fact that the system added polyphosphate inhibitors complicates the prediction of calcium carbonate precipitation. The EPA reports that no published forms of the Langelier Index or the CCPP "can take into account these inhibitory factors, particularly the presence of polyphosphates" (Control of Lead and Copper in Drinking Water, 1993). "Therefore, in systems containing polyphosphates either for corrosion control or for the prevention of unwanted calcium carbonate deposition, calculation of any of the widely published indices of calcium saturation or precipitation is invalid" (Control of Lead and Copper in Drinking Water, 1993). Although Thule does not currently add phosphates to the main base distribution system, they do add them at the BMEWS site. The Langelier Index and CCPP presented above should be interpreted with caution. The bottom line is that water with the characteristics of that at Thule is generally not a candidate for calcium carbonate precipitation.

Evaluate Viable Approaches

The PES report identifies phosphate inhibitors, silicate inhibitors, and pH/alkalinity adjustment as three viable approaches for the Thule system. Each of these approaches has

advantages and disadvantages given the water quality characteristics and distribution system materials at Thule.

Phosphate Inhibitors

The base has been adding phosphates to the water system for almost 40 years, but the effect of the phosphates on the distribution system has not been closely monitored. As mentioned previously, the base began adding polyphosphates to the water distribution system when the system was originally constructed in 1956. The idea behind adding the phosphates was to build a passivating film on the interior surface of the distribution pipes. Thule stopped adding phosphates to the main base water system in 1991. The base recently began adding a polyphosphate to a water distribution system in an area known as the J-Site, or BMEWS. They plan to add the phosphate to this site for three years. There are many problems associated with the use of polyphosphates reported in the literature.

The American Water Works Association Research Foundations (AWWARF) states that "polyphosphates are most effective in water of lower mineral content with a pH range of 6.5 to 7.5" (Lead Control Strategies, 1990). The water in the Thule system falls in this range. The AWWA goes on to state that the available information on polyphosphates indicates that they are ineffective in reducing lead levels, and could actually increase lead by complexation and solubilization of potentially protective films on pipes (Lead Control Strategies, 1990). The EPA states that "polyphosphates have demonstrated limited direct success toward lead and copper corrosion control" (LCR Guidance Manual, 1992). Holm and Schock corroborate the EPA conclusions regarding the link between polyphosphates and increased lead levels (1991). The main application of polyphosphates is the sequestration of dissolved metals. Polyphosphates have been shown to sequester dissolved iron and manganese, eliminating discoloration complaints. Additionally, polyphosphates are commonly used to sequester calcium to reduce its ability to precipitate in the distribution system or in the water treatment plant. Calcium in softening plants is a problem because it can encrust filter media (LCR Guidance Manual, 1992). A final disadvantage of polyphosphates is that they are expensive (Lead Control Strategies, 1990).

In summary, there is little evidence that polyphosphates are viable for corrosion control and their use for that purpose should not be pursued at Thule unless field tests have proven them effective. It is unfortunate that the base quit using polyphosphates in the main distribution system at the same time the Lead and Copper Rule was passed. If Thule had continued adding polyphosphate through the initial rounds of LCR sampling, then they could have determined definitively whether or not the treatment was effective. Since they stopped adding the phosphates in 1991 and did not perform the initial sampling until 1993, no conclusions can be drawn. Thule might consider referencing historical data, but it is unlikely that extensive Lead and Copper sampling was performed before the Lead and Copper Rule became law. Application of phosphates at the BMEWS site should be carefully evaluated to determine if it is an effective corrosion control treatment. However, since the BMEWS site contains steel pipes and most of

the main base system is HDPE pipes, limited conclusions can be drawn. One cautionary note from the AWWA Research Foundations is that "corrosion of steel pipe increases, particularly in soft, low-mineralized, low pH water, when free residual chlorine concentration exceeds 0.4 mg/L" (Lead Control Strategies, 1990). Thule should monitor chlorine residual in the BMEWS system closely.

Unlike polyphosphates, there are many examples of systems that have used orthophosphates to control lead and copper. There are some specific water quality characteristics necessary for successful application of orthophosphates. The first important consideration when considering orthophosphates is pH. In order for orthophosphates to be effective the system must have a stable pH between 7.4 and 7.8 (LCR Guidance Manual, 1992). At Thule, the source water has a pH of 6.6. The water in the distribution system is reportedly around 7.0-7.2 (There was no data provided on the pH in the distribution system. The 7.0-7.2 estimate comes from TSgt Brown in the Bio shop at Thule). Because the system does not fall in the required pH boundaries, orthophosphate is not a likely corrosion control technique.

pH/alkalinity Adjustment.

In the PES report, pH adjustment is eliminated as a corrosion control technique because of the potential for poor pH control in the interior piping. According to the LCR Guidance Manual the minimum solubility for both lead and copper occur at a pH over 9 and an alkalinity of 30-50 mg/L as $CaCO_3$. The PES report discounts pH adjustment primarily because the water is poorly buffered, however, they make no calculations as to the amount of dissolved inorganic carbonate in the water, which determines the systems buffering capacity. DIC can be estimated from pH and alkalinity. Using Table A-2 in appendix A of the LCR Guidance Manual, the DIC of the Thule water is 39 mg/L as $CaCO_3$, or 4.7 mg of Carbon per liter, as Carbon (mg C/L).

Using Appendix C in "Basic Chemistry & Corrosion Control Treatment To Meet The Safe Drinking Water Act (SDWA) Lead & Copper Rule" the DIC is estimated at 7.73 mg C/L. This value applies to a water at a pH of 6.6, an alkalinity of 20 mg/L, and a temperature of 10 degrees Celsius. The temperature difference partly accounts for the discrepancy between the two values. The same article claims that the optimal DIC for minimizing lead levels is 3-5 mg C/L. The AWWA Research Foundations reports that the minimum concentration of DIC necessary to provide sufficient buffering capacity is 2 mg/L (Lead Control Strategies, 1990). According to this estimate, Lake Crescent water has sufficient buffering capacity. Using the decision tree provided as Figure 6.9 in *Lead Control Strategies*, one arrives at pH adjustment as the desired corrosion control mechanism (see Appendix D). While this decision tree only provides approximate guidance, it does appear that the PES report discounts pH adjustment without giving the technique proper consideration.

Small water systems with low (3-6 mg C/L) but sufficient (> 2 mg C/L) DIC, often use pH adjustment as a corrosion control strategy. Raising the pH of the water to somewhere above 9, while maintaining a low alkalinity would minimize lead solubility. There are some important constraints to keep in mind when considering raising the pH to such a high level. Dissolved metals, if present in sufficient quantities, can precipitate when the pH is raised. The calcium and

DIC are low enough that calcium precipitation should not be a problem when pH is raised. However, iron and manganese values both exceed the secondary drinking water standards (0.30 mg/L for iron and 0.05 mg/L for manganese). If pH is raised above 9, these metals are likely to precipitate and cause more problems with water color. Since polyphosphates can sequester soluble iron and manganese, the BMEWS system may not be susceptible to this precipitation. The main base may encounter problems.

Another disadvantage of raising pH is that disinfection capacity is reduced at elevated pH's. Either the concentration of chlorine used or the allowed contact time would have to be increased to allow for adequate disinfection when pH is increased. Further, trihalomethanes, a suspected carcinogenic disinfection byproduct, can increase when pH is high. A final disadvantage of raising the pH to above 9 is that people are likely to reject the taste of an extremely basic water.

Although there are many disadvantages associated with raising the pH, it should be noted that many small systems have experienced corrosion control success by elevating pH to something less than 9. For example, lead solubility in a water at pH 6 is ten times higher than in a water at pH 7 (Basic Chemistry & Corrosion Control Treatment, 1995). Therefore, the system might solve its problems by raising pH from 6.6 at the source to somewhere around 8 in the distribution system. Medlar and Kim suggest pH of 8.0-8.5 as a rule of thumb for pH adjustment based on the experiences of large systems (1994).

Silicate inhibitors

The final viable corrosion control alternative to consider is addition of silicate inhibitors. This is the option recommended by PES in its April 1995 report. Although the method by which silicate inhibitors control corrosion is not very well understood, some systems have experienced success using them. The main advantage of silicate inhibitors over phosphate inhibitors is that they are effective over a much broader pH range. Some researchers believe that the only advantage gained by adding silicate inhibitors, in regards to corrosion control, is the increase in pH (Basic Chemistry & Corrosion Control Treatment, 1995). Sodium silicate, the chemical recommended by PES, is cited by the EPA in Control of Lead and Copper in Drinking Water for its ability to raise pH (1993). Sodium silicates are very safe for operators to handle and require relatively simple pumps for feeding. Another advantage of silicates is that they can enhance the rate of iron and manganese oxidation and complex the oxidized metals to prevent development of red or black water (Basic Chemistry & Corrosion Control Treatment, 1995). In order for silicate to sequester soluble metals, it must be added simultaneously with chlorine (Robinson, et al., 1992).

All sources indicate that passivation with silicate inhibitors is a slow process. Silicates must be added for two or three years before effectiveness should be judged. This is contrary to the PES report which states that the initial protective coating should develop as soon as the first 30 to 60 days. Some final notes on the use of silicate inhibitors are provided by the AWWA Research foundation. "Sodium silicates are poorly soluble in cold waters but are effective for inhibiting corrosion of galvanized steel and copper based metals in hot water systems. Too low a silicate dosage may intensify corrosion rates in some waters. Frequently, higher silicate dosages are required for lower pH conditions. Increasing the pH to between 7.5 and 8 with soda ash or

caustic will lower the silicate requirement and the overall cost of inhibitor treatment" (Lead Control Strategies, 1990). All inhibitors can combine with other water components and must be applied in sufficient doses to satisfy any background demand.

Recommend Optimal Treatment

It appears that the PES recommendation for the use of silicate corrosion inhibitors at Thule is plausible. Sodium silicate has the advantage of being effective over a much broader pH range than orthophosphate. A more practical solution might be to raise the pH of the water before it enters the distribution system. Commonly used pH boosters include caustics, sodium carbonate, or sodium bicarbonate. Caustics require small capital investment, but require many safety precautions (Medlar and Kim, 1994). Sodium carbonate and sodium bicarbonate are much safer chemicals to handle.

Once the pH is raised, the base should monitor the tap water to see if the elevated pH brings lead levels below the EPA action level. If the system still exceeds the action levels, then the base could try adding a sodium silicate inhibitor (or even orthophosphate inhibitor if pH stabilizes in the desired range).

One option not considered by PES, and generally not considered except in the smallest of systems (5 or fewer connections for example), is fixture replacement. The larger the system, the more cost inhibited this option becomes. Brass faucets are known to contribute a significant portion of lead to first draw tap samples. The first 100 mL of a sample represents the water that was sitting in the faucet (Gardels and Sorg, 1989). The next 400-500 mL of a sample represents water standing in the pipes near the faucet (Gardels and Sorg, 1989). Often, there are many lead soldered joints near the faucet, which means that this portion of the sample can contain high lead levels. Gardels and Sorg estimate that 60% to 75% of the lead leached from a common kitchen faucet is in the first 125 mL of the sample (1989). They further conclude that up to 95% of lead from a faucet is flushed out during the first 200-250 mL. Lee, et al., conclude that brass faucets contribute an average of one third of the lead in a 1 liter first draw sample (1989). The implication is that if a system can afford to replace brass faucets with lead free faucets, it might go a long way toward solving its lead problems without ever adjusting water quality.

In summary, the PES recommendation for addition of sodium silicate is the best option given the current state of knowledge. However, Thule should make an effort to further define the system before any large capital investment is made. Some recommended actions are as follows:

1. The base must define the system pH over the entire distribution system. The use of orthophosphates, which is a common and very well understood corrosion control technique, might be possible if better information was available on pH stability. Measurements of pH can be made with a commercially available hand held pH meter. Many small systems have experienced success by boosting pH into the desired range and then adding orthophosphate inhibitors. This technique

is particularly useful because pH is not elevated to the extreme ranges where metals precipitation, and other reported problems, occur.

2. The base should research historical data to determine what information is available on the 35 years of phosphate addition (1956-1991). If Thule can locate lead and copper sampling results from the time period when polyphosphate inhibitors were added, then some conclusions could be drawn. Specifically, Thule could determine if the polyphosphates were effective corrosion inhibitors. The base should also investigate the reasons, if any, that the chemicals were added for 35 years, and what effect they had on water quality.

3. The base should perform some rudimentary sampling to determine the contribution of brass faucets to high lead levels. The AWWA Research Foundations provides "Identification-oriented water quality monitoring protocols" in Lead Control Strategies (see Appendix E). The goal of sampling using these protocols is to isolate the cause of high lead levels. If it is determined that certain fixtures are contributing a large percentage of lead to first draw samples, then the base might consider replacing these fixtures.

4. The base should make an effort to compile sampling data into a computerized database or spreadsheet. This will allow personnel to track water quality trends and will alert personnel when a sample result is out of the ordinary.

Appendix F contains a preliminary estimate of the cost for AL/OEBW to accomplish the recommended sampling and analysis.

CONCLUSION

This report provides an evaluation of the PES Desktop Report for Thule Air Base, Greenland. The report provides detail on why certain corrosion control techniques are not appropriate at Thule. Although the PES report failed to explain many important details, the recommendation for the use of silicate inhibitors is sound. However, there are many complicating factors. These factors introduce a certain degree of uncertainty into any recommendation. The use of polyphosphates in part of the distribution system is one such factor. A more completely defined water distribution system will help Thule solve corrosion problems and also help in evaluating water quality on a continuing basis.

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APPENDIX A

GREENLAND CONTRACTORS
Thule Air Base
Environmental Engineering

11 October, 1996
GC/ESEM
FY97-016

Thule Lead non-compliance test from July 1993 to September 1996

FACILITY	LEAD CONCENTRATION, mg/L							
	July 93	Feb. 94	July 94	Feb. 95	July 95	July 96	Sep. 96	Sep.96*
Bldg. #0097, High-rise	0.003	0.011	0.055	0.006	0.006	0.016	0.038	0.002
Bldg. #0107, Dining Hall	0.001	0.001	0.001	0.001	0.001	0.001	N/A	N/A
Bldg. #0115, Flat-top	0.003	0.001	0.003	0.001	N/A	0.002	N/A	N/A
Bldg. #0127, Flat-top	0.001	0.001	0.001	0.001	0.001	0.003	N/A	N/A
Bldg. #0245, Flat-top	N/A	0.018	0.020	0.018	0.030	0.024	1.15	0.007
Bldg. #0256, Flat-top	N/A	0.001	0.001	0.001	0.002	0.005	N/A	N/A
Bldg. #0325, Flat-top	N/A	0.001	0.001	0.001	0.001	0.001	N/A	N/A
Bldg. #0463, PDO	N/A	0.018	0.022	0.002	0.003	0.084	0.008	0.003
Bldg. #0580, Vehicle Maintenance	N/A	0.002	0.028	0.004	0.007	0.149	1.35	0.024
Bldg. #0608, Hangar #4	0.006	0.001	0.002	0.001	0.003	0.006	N/A	N/A
Bldg. #0619, Base Ops.	N/A	0.001	0.001	0.001	0.001	0.001	N/A	N/A
Bldg. #0630, Hangar #10	N/A	0.011	0.002	0.002	0.003	0.014	N/A	N/A
Bldg. #0707, Flat-top	N/A	0.021	0.002	0.001	0.002	0.002	N/A	N/A
Bldg. #0708, High-rise	0.007	0.003	0.016	0.003	0.008	0.092	0.107	0.004
Bldg. #0750, Hospital	0.018	0.002	0.011	0.007	0.005	0.002	N/A	N/A
Bldg. #0760, DLO Resid.	0.016	0.018	0.012	0.006	0.010	0.019	0.061	0.001
Bldg. #0774, Flat-top	N/A	0.018	N/A	0.012	0.008	0.003	N/A	N/A
Bldg. #0801, Consolidation Material Control	0.001	0.022	0.007	0.005	0.006	0.020	N/A	N/A
Bldg. #0836, Vehicle Manegement	N/A	0.003	0.012	0.132	0.005	0.014	N/A	N/A
Bldg. #0935, Base Supply	N/A	0.001	0.065	0.002	0.003	0.003	N/A	N/A
Bldg. #1400, Truck Fill	0.010	0.018	0.010	0.005	0.023	0.013	N/A	N/A

***Sep. 96 results, samples drawn after 5-10 min of running water**
Action level: 0.015 mg/L as 90th percentile
Detection limit: 0.001 mg/L, results of 0.001 mg/L may contain less

DEPARTMENT OF THE AIR FORCE
12th Space Warning Squadron
APO, AE 09704-5000

26 May 94

MEMORANDUM FOR Pacific Environmental Services (PES)

FROM: 12 SWS/SGB
750 Hospital Loop
Unit # 82501
APO AE 09704-5000

SUBJ: Potable Water Characteristics and Distribution System Materials of Construction Information

1. The subject information, as discussed with Bob Forbes on 6 April 1994, is provided for the Thule AB drinking water study.

a. Pipe materials used base wide: Exterior - Most pipe is high density polyethylene, the rest is standard steel. Interior - most if not all consists of copper pipe and lead solder.

b. Copper Piping Installation Date: 1956 through 1957, by the Army Corps of Engineers. There have been minor ongoing modifications since this time

c. Faucet, Gooseneck, Elbow, and Valve Materials: All of these are chrome plated brass or copper (GSA catalog materials)

d. Storage Tank Materials: Steel with an internal epoxy coating.

e. Filtration System: Sand Filtration (sand and carbon-type mixture) used on a filtration system referred to as a Hydrolit CAI. The system is manufactured and replenished by a Danish company named "SILHORKO". The filters utilize 50 bags (1.5 tons) of sand material and is changed according to the turbidity readings.

f. Water Treatment Used: Chlorination for the entire system. For the branch that goes to J-Site (BMEWS), Hexameta Phosphate is added in addition to chlorine. The phosphate is added because the steel pipe is new and is being treated to create an inner coating for a three year period.

2. Enclosed please find the Blueprints for the water supply system here at Thule. If you require additional information or need clarification please contact me, TSgt Soriano, at DSN 268-1211, ext 2782 Fax: 3460, or commercial telephone number 01129950636.

MANUEL J. SORIANO, TSgt, USAF
Bioenvironmental Engineering Services
Quality Assurance Evaluator

	Thule AFB Lead and Copper Results					
	July	93	Feb	94	July	94
Bldg No	Cu	Pb	Cu	Pb	Cu	Pb
Lake	0.1	0.001	0.02	0.001		
1400	0.2	0.01	0.02	0.018	0.02	0.01
97	1.5	0.003	0.08	0.011	0.12	0.055
105	2.1	0.067				
107	0.1	0.001	0.02	0.001	0.02	0.001
115	0.8	0.003	0.05	0.001	0.08	0.003
126	0.8	0.051				
127	1.5	0.001	0.28	0.001	0.2	0.001
245			0.25	0.018	0.23	0.02
256			0.12	0.001	0.062	0.001
325			0.08	0.001	0.064	0.001
334	0.2	0.004				
362	0.7	0.006				
367	0.9	0.072				
426			0.27	0.001		
463			0.15	0.018	0.133	0.022
580			0.04	0.002	0.062	0.028
608	0.2	0.006	0.03	0.001	0.03	0.002
619			0.02	0.001	0.02	0.001
630			0.05	0.011	0.039	0.002
707	0.6	0.021	0.06	0.007	0.032	0.002
708	0.4	0.007	0.02	0.003	0.058	0.016
750	0.9	0.018	0.03	0.002	0.02	0.011
760	0.2	0.016	0.09	0.018	0.064	0.012
774			0.64	0.018		
801			0.22	0.022	0.158	0.007
836			0.04	0.003	0.148	0.012
837	0.1	0.001				
935			0.02	0.001	0.014	0.065

APPENDIX B

Table 3-3a. Constraints Worksheet for pH/Alkalinity or Calcium Adjustment Treatment Alternatives

Adjusting pH/Alkalinity and/or calcium for corrosion control typically consists of increasing their levels to generate favorable conditions for lead and copper passivation or calcium carbonate precipitation.

A. National Primary Drinking Water Regulations Constraints

Rule	Constraint
Surface Water Treatment Rule	Reduces inactivation effectiveness of free chlorine if pH adjusted before disinfection.* Potential for interference with dissolved ozone measurements. May increase turbidity from post-filtration precipitation of lime, aluminum, iron, or manganese.
Groundwater Disinfection	Reduces inactivation effectiveness of free chlorine if pH adjusted before disinfection.* Potential for interference with dissolved ozone measurements.
Disinfection Byproducts	Higher THM concentrations from chlorination if pH adjusted before disinfection.* Reduced effectiveness of some coagulants for precursor removal if pH adjusted before coagulation.*
Coliform Rule	Potential for higher total plate counts, confluent growth, or presence of total coliforms when chlorination is practiced.
Radionuclides	In-plant adjustments may affect removal of radioactive particles if precipitation techniques are used for coagulation or softening. Removal of radionuclides during softening may be linked to the degree of softening. Modifying softening practices to achieve corrosion control could interfere with removals.

Table 3-3a. Constraints Worksheet for pH/Alkalinity or Calcium Adjustment Treatment Alternatives (continued)

B. Functional Constraints
Increased potential for post-filter precipitation may give undesirable levels of aluminum, iron, or manganese.
Process optimization is essential. Additional controls, chemical feed equipment, and operator attention may be required.
Multiple entry points will require pH/Alkalinity adjustment at each entry location. Differing water qualities from multiple sources will require adjusting chemical doses to match the source.
The use of sodium-based chemicals for alkalinity or pH adjustments should be evaluated with regard to the total sodium levels acceptable in the finished water.
Users with specific water quality needs, such as health care facilities, should be advised of any changes in treatment.
Excessive calcium carbonate precipitation may produce "white water" problems in portions of the distribution system.
It may be difficult to produce an acceptable coating of calcium carbonate on interior piping for large distribution systems. High CCPP levels may eventually lead to reduced hydraulic capacities in transmission lines near the treatment facility while low CCPP values may not provide adequate corrosion protection in the extremities of the distribution system.

- Unless operating restraints dictate otherwise, the optimum location for pH adjustment is after disinfection and near the entrance to the distribution system. If quicklime is used to adjust pH, for example, it needs to be added prior to filtration so inert material does not accumulate in the clearwell or enter the distribution system.

Table 3-3b. Constraints Worksheet for Inhibitor Treatment Alternatives

Corrosion inhibitors can cause passivation of lead and copper by the interaction of the inhibitor and metal components of the piping system.

A. National Primary Drinking Water Regulations Constraints

Rule	Constraint
Surface Water Treatment Rule	The application of phosphate-based inhibitors to systems with existing corrosion byproducts can result in the depletion of disinfectant residuals within the distribution system. Additionally, under certain conditions phosphate-based inhibitors may stimulate biofilms in the distribution system.
Groundwater Disinfection	Same as above.
Disinfection Byproducts	No apparent effects.
Coliform Rule	If corrosion byproducts are released after the application of inhibitors, coliforms may be detected more frequently and confluent growth is more likely.
Radionuclides	No apparent effects.

B. Functional Constraints

Potential post-filtration precipitation of aluminum.

Consumer complaints regarding red water, dirty water, color, and sediment may result from the action of the inhibitor on existing corrosion byproducts within the distribution system.

Multiple entry points will require multiple chemical feed systems.

The use of sodium-based inhibitors should be evaluated with regard to the total sodium levels acceptable in the finished water.

The use of zinc orthophosphate may present problems for wastewater facilities with zinc or phosphorus limits in their NPDES permits.

Users with specific water quality needs, such as health care facilities, should be advised of any treatment changes.

NOTE: If pH adjustment is necessary to produce an effective pH range for the inhibitor, then the constraints in Table 3-3a would also need to be evaluated.

APPENDIX C

The RTW Model Ver. 3.0 ID: **Thule Air Base, Greenland**

STEP 1: Enter initial water characteristics.

Measured TDS	**66**	mg/L
Measured temperature	**2**	deg C
Measured pH	**6.6**	
Measured alk, as CaCO3	**20**	mg/L
Measured Ca, as CaCO3	**6.4**	mg/L
Measured Cl	**0**	mg/L
Measured SO4	**0**	mg/L

For CT and TTHM functions enter current:

Treated water pH		
Chlorine residual		mg/L
Chlorine or hypochlorite dose as chlorine equivalent		mg/L

STEP 2: Enter amount of each chemical to be added (expressed as 100% chemical). Press Alt+C to select chemicals for this list.

Alum 50% solution	**0**	mg/L
Calcium carbonate	**0**	mg/L
Carbon dioxide	**0**	mg/L
Caustic soda	**0**	mg/L
Chlorine gas	**0**	mg/L
Hydrochloric acid	**0**	mg/L
Hydrofluosilicic acid	**0**	mg/L
Lime (slaked)	**0**	mg/L
Soda ash	**0**	mg/L
Sodium bicarbonate	**0**	mg/L

STEP 3: Adjust at Step 2 until interim water characteristics meet your criteria.

Theoretical interim water characteristics			Desired	Theoretical interim water characteristics			Desired
Interim alkalinity	20	mg/L	> 40 mg/L	Interim pH	6.60		6.8-9.3
Interim Ca, as CaCO3	6	mg/L	> 40 mg/L	Precipitation potential	-35.18	mg/L	4-10 mg/L
Alk/(Cl+SO4)	N/A		> 5.0	Langelier index	-3.30		>0

Press PAGE DOWN for additional initial, interim and final water characteristics if desired.

Calculated initial water characteristics

Initial acidity	55	mg/L
Initial Ca sat, as CaCO3	12758	mg/L
Initial DIC, as CaCO3	75	mg/L

Theoretical interim water characteristics

Interim acidity	55	mg/L
Interim Ca sat, as CaCO3	12758	mg/L
Ryznar index	13.20	
Interim DIC, as CaCO3	75	mg/L
Aggressiveness Index	8.71	

Theoretical final water characteristics after CaCO3 precipitation

Final alkalinity	N/A	mg/L
Final Ca	N/A	mg/L
Final acidity	N/A	mg/L
Final pH	N/A	
Final DIC, as CaCO3	N/A	mg/L

Press PAGE UP to review measured initial water characteristics, chemical addition quantities and additional interim water characteristics.

CT and TTHM Results

Required chlorine residual to maintain current level of giardia inactivation	N/A	mg/L
Estimated maximum total trihalomethane concentration change from current level	N/A	%

The RTW Model Ver. 3.0 ID: **Thule Air Base, Greenland**

STEP 1: Enter initial water characteristics.

Measured TDS	**66**	mg/L
Measured temperature	**2**	deg C
Measured pH	**6.6**	
Measured alk, as CaCO3	**20**	mg/L
Measured Ca, as CaCO3	**6.4**	mg/L
Measured Cl	**0**	mg/L
Measured SO4	**0**	mg/L

For CT and TTHM functions enter current:

Treated water pH	
Chlorine residual	mg/L
Chlorine or hypochlorite dose as chlorine equivalent	mg/L

STEP 2: Enter amount of each chemical to be added (expressed as 100% chemical). Press Alt+C to select chemicals for this list.

Alum 50% solution	**0**	mg/L
Calcium carbonate	**40**	mg/L
Carbon dioxide	**0**	mg/L
Caustic soda	**0**	mg/L
Chlorine gas	**0**	mg/L
Hydrochloric acid	**0**	mg/L
Hydrofluosilicic acid	**0**	mg/L
Lime (slaked)	**0**	mg/L
Soda ash	**0**	mg/L
Sodium bicarbonate	**0**	mg/L

STEP 3: Adjust at Step 2 until interim water characteristics meet your criteria.

Theoretical interim water characteristics			Desired	Theoretical interim water characteristics			Desired
Interim alkalinity	60	mg/L	> 40 mg/L	Interim pH	9.25		6.8-9.3
Interim Ca, as CaCO3	46	mg/L	> 40 mg/L	Precipitation potential	4.82	mg/L	4-10 mg/L
Alk/(Cl+SO4)	N/A		> 5.0	Langelier index	0.69		>0

Press PAGE DOWN for additional initial, interim and final water characteristics if desired.

Calculated initial water characteristics

Initial acidity	55	mg/L
Initial Ca sat, as CaCO3	12758	mg/L
Initial DIC, as CaCO3	75	mg/L

Theoretical interim water characteristics

Interim acidity	55	mg/L
Interim Ca sat, as CaCO3	11	mg/L
Ryznar index	7.87	
Interim DIC, as CaCO3	115	mg/L
Aggressiveness Index	12.69	

Theoretical final water characteristics after CaCO3 precipitation

Final alkalinity	55	mg/L
Final Ca	42	mg/L
Final acidity	55	mg/L
Final pH	8.66	
Final DIC, as CaCO3	110	mg/L

Press PAGE UP to review measured initial water characteristics, chemical addition quantities and additional interim water characteristics.

CT and TTHM Results

Required chlorine residual to maintain current level of giardia inactivation	N/A	mg/L
Estimated maximum total trihalomethane concentration change from current level	N/A	%

APPENDIX D

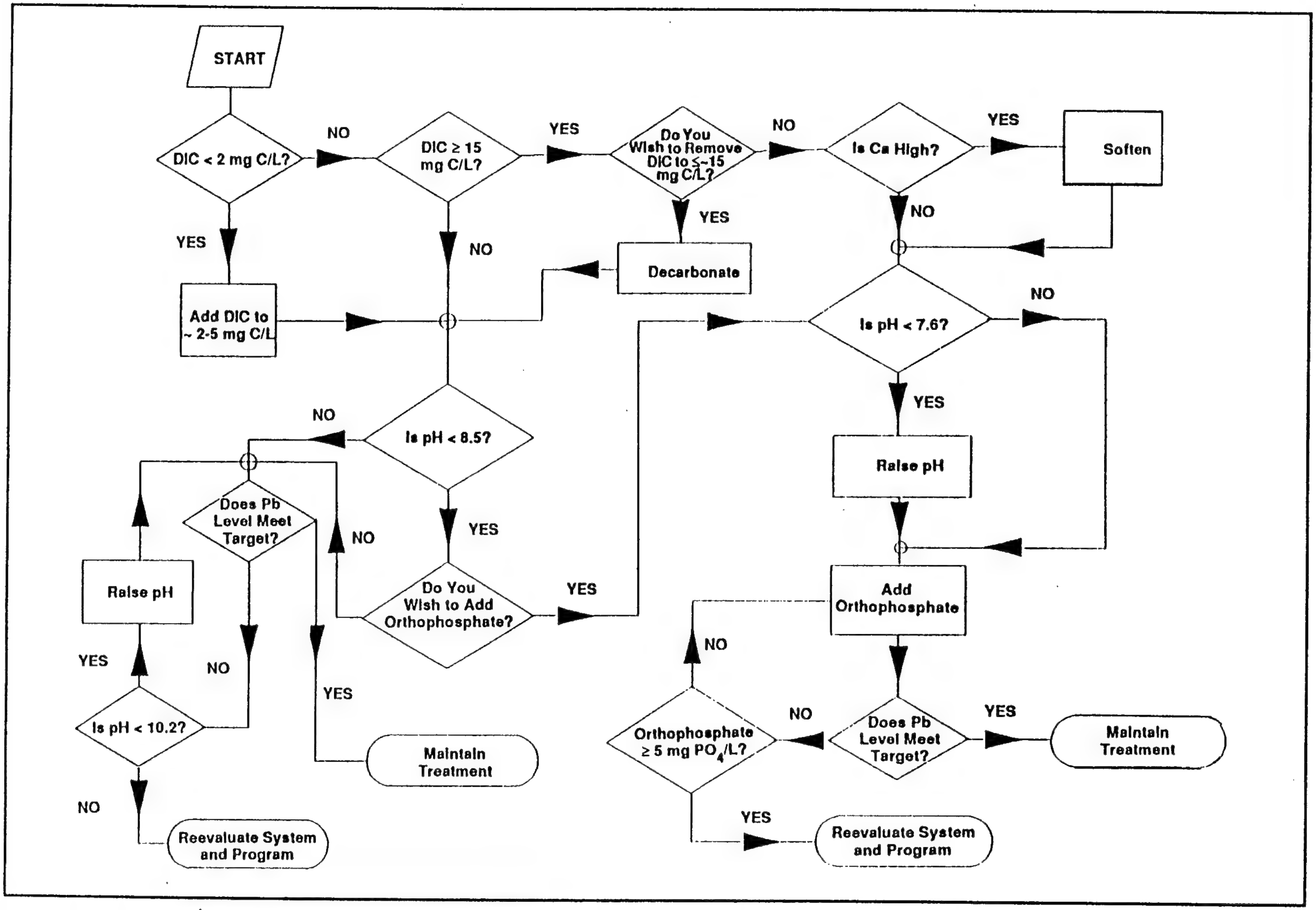

Figure 6.9 Approximate decision tree for the selection of treatment options among pH, DIC, and orthophosphate dosage

APPENDIX E

Table 5.1 Identification-oriented water quality monitoring protocols

Lead source to be identified	Sample locations	Sample collection procedure	Sample volume
Distribution system sources	Cold water tap	Flush • for 10 minutes at a moderate flowrate; • until a constant cold temperature is detected, then for an additional 5 minutes at a moderate flowrate; or • until calculated volume from home plumbing, service line, and service connection has been flushed.	1 L
Gooseneck	Cold water tap	Collect after water has been standing for 8–18 hours • Flush until calculated volume from home plumbing and service line has been flushed, then collect sample. • Collect consecutive 100 mL samples to identify slug from gooseneck.	Calculated volume for gooseneck 100 mL
	Install sample tap on service line at the meter or as close to the connection with the home piping as possible	Collect after water has been standing for 8–18 hours. Flush calculated volume from the service line to the gooseneck.	Calculated volume for gooseneck, based on inside diameter and length
Service line	Cold water tap	Collect after water has been standing for 8–18 hours. Flush until calculated volume from home plumbing has been flushed; collect sample.	1 L*
	Install sample tap on service line at the meter or as close to connection with the home piping as possible	Collect after water has been standing for 8–18 hours. Flush until calculated volume from home plumbing has been flushed; collect sample.	1 L*
Interior home plumbing (soldered joints)	Cold water tap	Collect after water has been standing for 8–18 hours. 1) To include faucet 2) To exclude faucet: Collect first 100 mL, then collect next 900 mL. 900 mL sample represents home plumbing.	 1 L 100 mL, then 900 mL
Faucets	Cold water tap	Collect after water has been standing for 8–18 hours.	100 mL

* Volume can be adjusted downward for service lines shorter than 15 to 30 ft (depending on inside diameter); for example, in order to get a 1-L sample from a 1/2-in. diameter service line, the service line would need to be 25.6 ft long. For a 3/4-in. diameter line, the length would need to be 11.5 ft in order to get a 1-L sample.

APPENDIX F

Cost estimate for Thule field work

Travel	Price	Quantity		Total
Airfare	$950.00	2		$1,900.00
Per Diem	$211.00	20		$4,220.00
Misc.	100	2		$200.00

Total Travel Cost **$6,120.00**

Labor	Price	Quantity		Total
Preparation	$40.00	24		$960.00
Field work	$40.00	160		$6,400.00
Database	$40.00	40		$1,600.00
Report	$40.00	40		$1,600.00

Total Labor Cost **$10,560.00**

Samples	Price	Source Water	Distribution System	Total Samples	Total Cost
Lead	$20.00	2	60	62	$1,240.00
Copper	$8.00	2	60	62	$496.00
Manganese	$8.00	2	60	62	$496.00
Iron	$8.00	2	60	62	$496.00
Magnesium	$8.00	2	60	62	$496.00
Sodium	$8.00	2	60	62	$496.00
Calcium	$8.00	2	60	62	$496.00
Chlorine	$0.00	2	60	62	$0.00
pH	$0.00	2	60	62	$0.00
Alkalinity	$10.00	2	60	62	$620.00
Temperature	$0.00	2	60	62	$0.00
Conductivity	$15.00	2	0	2	$30.00
Hardness	$20.00	2	0	2	$40.00
TDS	$15.00	2	0	2	$30.00
PO4 (total)	$10.00	0	60	60	$600.00
PO4 (ortho)	$10.00	0	60	60	$600.00

Total Analytical Cost **$6,136.00**

Cost Summary

Travel	**$6,120.00**
Labor	**$10,560.00**
Analytical	**$6,136.00**
Total	**$22,816.00**

Assumptions

2 person survey team
10 day trip (may be more depending on flight availability)
Collect 3 different samples at 20 different locations
Collect 2 source water samples
Labor hours are for preparation, field work, and report preparation
Airfare to Philadelphia ($176) then military hop to Thule ($774)
Per Diem cost will be significantly less if government quarters are available

APPENDIX G

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	17 April 1995	Final

4. TITLE AND SUBTITLE
Desktop Report for Corrosion Control Treatment Validation

5. FUNDING NUMBERS
Contract No. F33615-89-D-4000
Delivery Order No. 0041

6. AUTHOR(S)
Wayne Westbrook
Robert Forbes

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Pacific Environmental Services, Inc.
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Herndon, VA 22070

8. PERFORMING ORGANIZATION REPORT NUMBER
F041

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory/OEBW
2402 E Drive
Brooks AFB, TX 78235-5114

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
N/A

11. SUPPLEMENTARY NOTES
This report was prepared for Thule AB, Greenland as directed by the 21st Medical Group, Bioenvironmental Engineering, Peterson AFB, CO.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unlimited

12b. DISTRIBUTION CODE
N/A

13. ABSTRACT *(Maximum 200 words)*
On 7 Jun 91, US EPA promulgated National Primary Drinking Water Regulations (NPDWRs) for lead and copper (referred to here as the Lead and Copper Rule [LCR]). The LCR requires public water systems (PWSs) to either demonstrate that existing lead and copper levels in consumers' tap water are below acceptable levels (the action level [AL]), or that an optimal corrosion control treatment technique has been implemented to reduce lead and copper levels to below the AL.

Thule AB, Greenland exceeded the action level for lead and for copper. Thule AB must submit recommendations for optimal corrosion control to Space Command. Recommended corrosion control treatment techniques will be based on a desktop evaluation.

This report reviews the installation's lead and copper sampling history, source water quality, water treatment processes, results of water quality parameter sampling, and information concerning the water distribution system. Using EPA protocols spelled out in the LCR Guidance Manuals, a desktop treatment evaluation is presented herein.

14. SUBJECT TERMS
Corrosion Control, Drinking Water, Lead and Copper Rule

15. NUMBER OF PAGES
92

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

DESKTOP REPORT FOR

CORROSION CONTROL TREATMENT VALIDATION THULE AIR BASE, GREENLAND

Contract No. F33615-89-D-4000
Delivery Order No. 0041

Prepared for

United States Air Force
Armstrong Laboratory
and
21st MG/SGPB
Peterson Air Force Base

18 April 1995

Submitted by

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NOTICE

Pacific Environmental Services, Inc. has prepared this report for the United States Air Force for the purpose of aiding in the implementation of the Safe Drinking Water Act. It is not an endorsement of any product. The views expressed herein are those of the contractor and do not necessarily reflect the official views of the publishing agency, the United States Air Force, or the Department of Defense.

DESKTOP REPORT FOR
CORROSION CONTROL TREATMENT VALIDATION
THULE AB, GREENLAND

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DESKTOP REPORT
FOR
CORROSION CONTROL TREATMENT VALIDATION
THULE AB, GREENLAND

AUTHORIZATION

The Department of the Air Force has authorized Pacific Environmental Services, Inc. (PES) to prepare a Desktop Report for Corrosion Control Treatment Validation at Thule AB by Delivery Order 41 to Contract F33615-89-D-4000. The report was directed by the 21st Medical Group, Bioenvironmental Engineering, Peterson AFB, Colorado.

SCOPE OF WORK

The United States Environmental Protection Agency (USEPA) was required to develop drinking water standards for contaminants which impose potential health risks under the 1986 Amendments to the Safe Drinking Water Act. The Lead and Copper Rule (LCR) was promulgated by the USEPA to set standards for lead and copper in drinking water. The United States Air Force (USAF) Space Command regulates the implementation of the rule for the Thule AB (Base) water system.

This Desktop Report is required because the Base exceeded both the copper and lead action levels on laboratory testing in July 1993 of 16 sampling sites for the LCR. There are less than 1,000 personnel assigned to the Base, which classifies the Base as a small public water supply for purposes of LCR monitoring.

The Desktop Report follows the seven steps described in the EPA 81-B-92-002, Lead and Copper Rule Guidance Manual issued by the USEPA (hereafter called the LCR Manual). These seven steps consist of:

Step 1	Define Existing Conditions
Step 2	Monitor Source Water
Step 3	Define Constraints

Step 4 Identify Corrosion Control Priorities

Step 5 Eliminate Unsuitable Approaches

Step 6 Evaluate Viable Approaches

Step 7 Recommend Optimal Treatment

Each of the seven steps will be discussed in more detail in this Desktop Report. The information is summarized in the Desktop Evaluation Short Form for Small and Medium PWS Treatment Recommendations included as Appendix A of this report. The Checklist for PWS Desk-Top Evaluations, also taken from the LCR Manual, is found in Appendix B.

The LCR Manual logic diagram, shown in Figure 1 on the next page, presents the process involved in performing desk-top evaluations for selecting optimal treatment. This procedure initially eliminates any infeasible treatment approaches and then determines the water quality conditions defining optimal corrosion control treatment. Among the resulting alternatives, optimal treatment is to be selected based on the following criteria:

- the results of lead and copper tap sampling;
- corrosion control performance based on either the reductions in lead and copper solubilities or the likelihood of forming protective scales;
- the feasibility of implementing the treatment alternative on the basis of the constraints identified;
- the reliability of the alternative in terms of operational consistency and continuous corrosion control protection; and,
- the estimated costs associated with implementing the alternative treatments.

STEP 1 - DEFINE EXISTING CONDITIONS

Base

Thule Air Base is located in northwestern Greenland, approximately 950 miles south of the North Pole and 800 miles north of the Arctic Circle (Figure 2). The base is home to the 12th Space Warning Squadron (12 SWS), which provides warning of ballistic missile raids against the United States and Canada to the unified and specified commands. In addition, Detachment 3, 2nd Satellite Tracking Group,

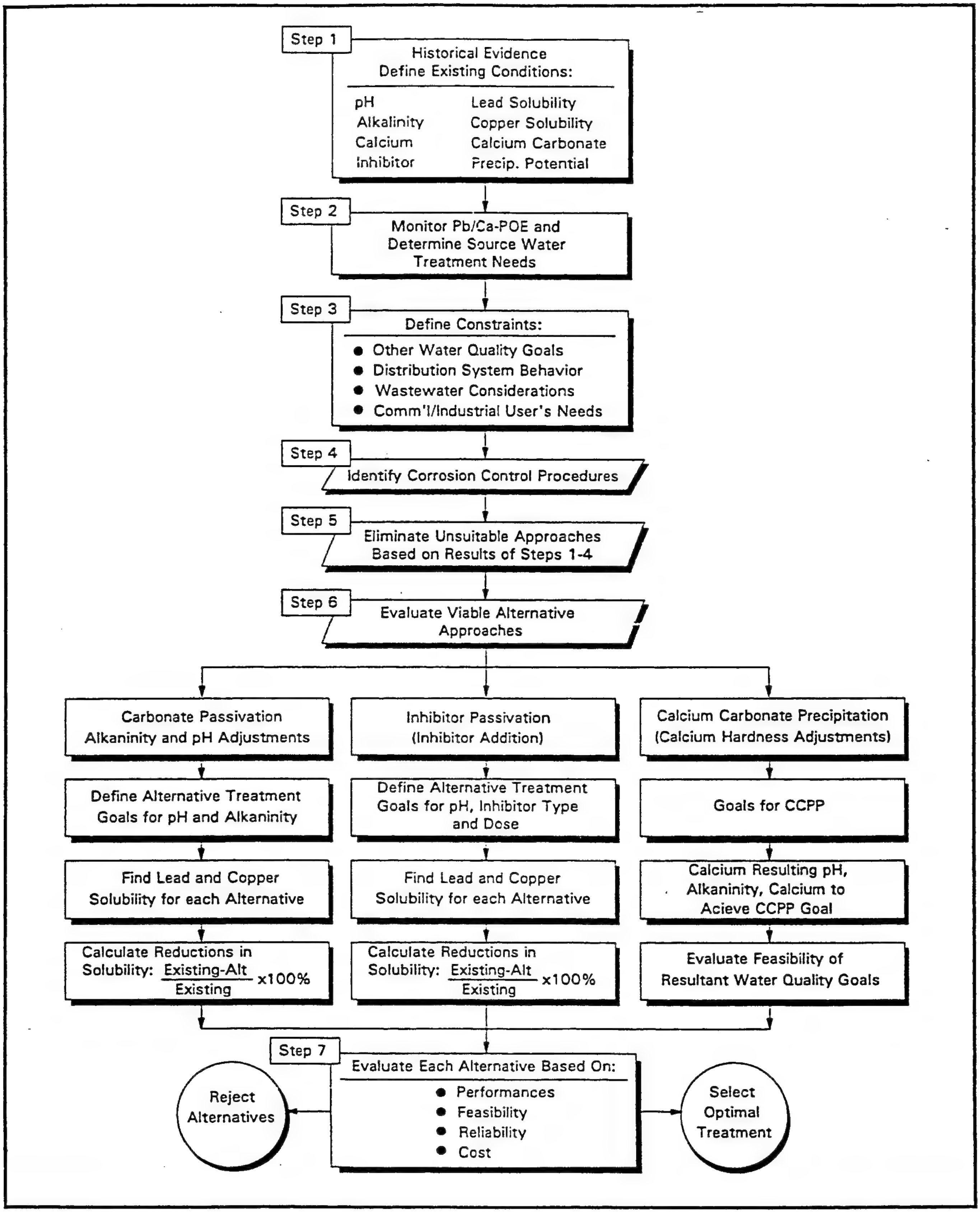

Figure 1 Logic Diagram for Evaluating Alternative Corrosion Control Approaches

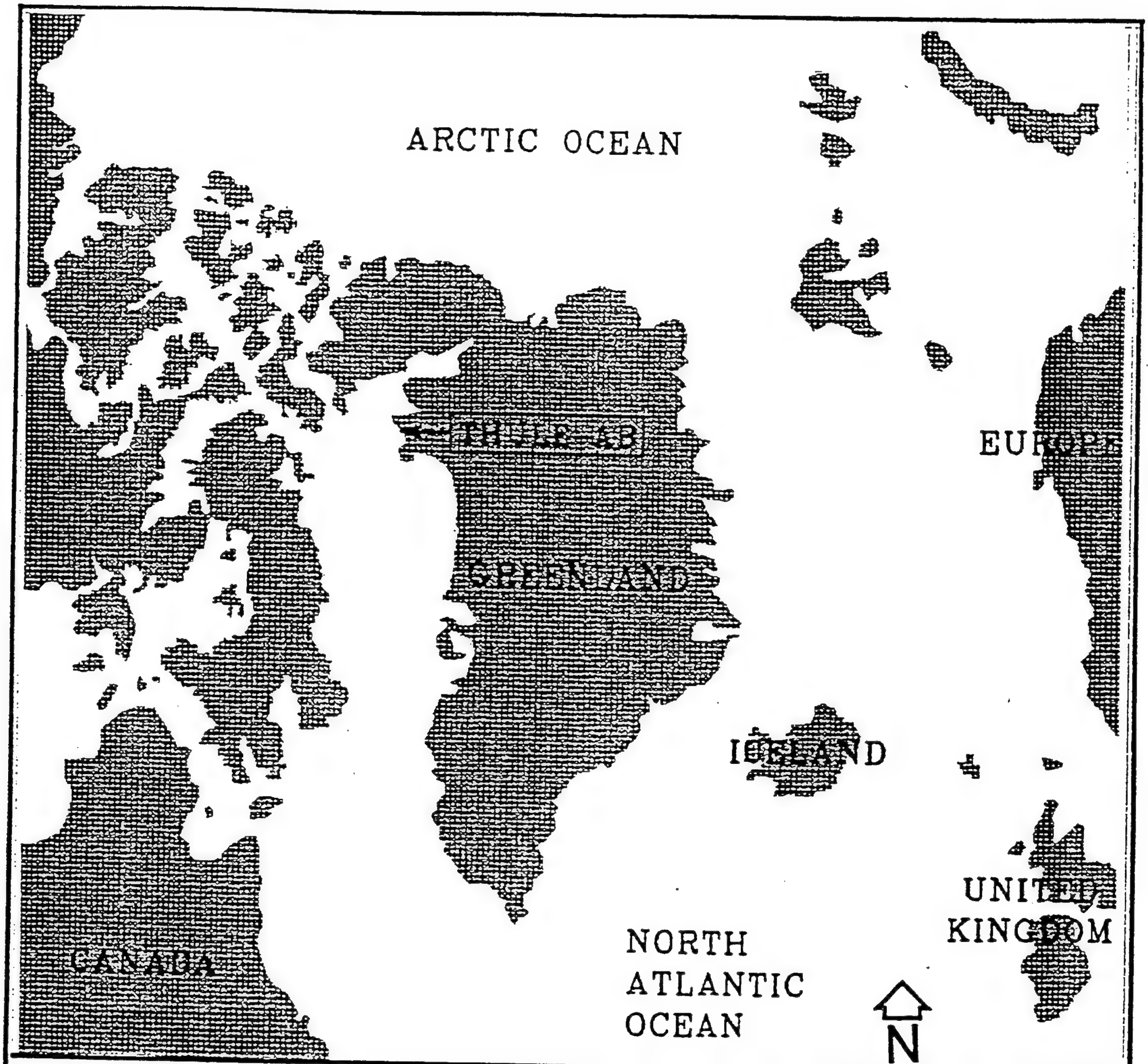

FIGURE 2 LOCATION MAP

monitors and tracks earth satellite vehicles in support of space surveillance operations. The Base is also tasked with supporting United States, allied, and international military, scientific, and logistic operations conducted in northern Greenland.

The Base obtains its water from a surface supply, Lake Crescent. The water is treated in a water filtration plant which is sited adjacent to the lake.

Water temperature at this point is about 2 °C (36 °F). Suspended matter in the water withdrawn from the lake is removed using a Hydrolit CAI sand filtration (sand and carbon-type mixture) system manufactured by SILHORKO, a Danish company. The filters use 1.5 tons of sand material, which is changed when turbidity reaches preset limits.

The filtered water is chlorinated at the water treatment plant and then pumped 10 miles to storage tanks on the main base. The storage tanks are steel with internal epoxy coatings. The water temperature is raised to between 5 and 10 ° C using heating equipment in the storage tank area.

Pipe Materials

Chlorinated water is piped 10 miles to the distribution storage tanks on base. The transmission piping is 8-inch diameter high density polyethylene (HDPE). Most of the exterior piping used on the Base is HDPE and varies in size from 8-inch to 2-inch. Most, if not all, of the interior piping consists of copper pipe with lead soldered joints. The copper piping was installed by the Army Corps of Engineers in 1956 and 1957. There have been minor modifications since that time. All faucets, goosenecks, elbows, and valve materials are chrome plated brass or copper (GSA catalogue materials). Brass faucets and fittings often contain significant percentages of lead which can leach out of the brass and contribute to the lead measured in the first-draw samples required for LCR testing.

The water distribution branch that goes to the J-Site (BMEWS) is constructed of new steel pipe that was recently installed. Hexameta phosphate is being added to this branch piping for a three-year period to create an inner coating.

LCR Testing

Initial sample collection was performed on 30 July 1993. In addition to the source water, water samples were collected from 16 sites located throughout the Base. Laboratory testing for copper and lead was performed by Armstrong Laboratory at Brooks AFB using USEPA approved test methods. The copper concentration in the 90th percentile sample was 2.0 mg/L. The lead concentration in the 90th percentile sample was 0.05 mg/l. These exceed the LCR action levels of 1.3 mg/L for copper and 0.015 mg/l for lead. Results of these tests are presented in Appendix C.

Tap water samples were collected from 22 sites plus the source water on 2 February 1994. Two of the three sites which had exceeded the copper action level in the July 1993 sampling were included in this round of sampling. Again, the 90th percentile value exceeded the lead action level of 0.015 mg/l. Copper did not exceed action levels. Analyses for lead and copper were performed by Armstrong Laboratory. The results are presented in Appendix C.

Tap water samples were collected from 20 sites in July 1994. Two of the three sites which had exceeded the copper action level in the July 1993 sampling were included in this round of sampling. Once again, the 90th percentile value exceeded the lead action level of 0.015 mg/l and copper did not exceed action levels. Analyses for lead and copper were performed by Armstrong Laboratory. The results are presented in Appendix C.

The data for copper concentrations show that the action level was not exceeded in either of the last two rounds of sampling. The highest copper concentration found in these tests was 0.64 mg/L, less than half the action level of 1.3 mg/L. It would appear, therefore, that excessive copper levels are not a continuing problem and should not be the focus of the corrective actions.

lead

The data for lead concentrations is substantially different than for copper. The action levels for lead were exceeded in all three rounds of sampling. There is no clear pattern to the copper levels in the various buildings. The fact that high lead levels were found ~~in a~~ particular building during one round of sampling does not seem to be related to the value that may be found during subsequent samplings. There is a suggestion in the data that lead levels may be higher in the summer months than in colder months (summer maxima lead concentrations are about 0.07 mg/L versus 0.02 mg/L in winter).

Source water (Lake Crescent) copper and lead concentrations were below the detection limits for all sampling periods.

STEP 2 - MONITOR SOURCE WATER

The Lake Crescent water, as determined at the point-of-entry to the Base, is a low temperature (~ 2 °C), low pH (~6.8, temperature corrected), low alkalinity (~20 mg/L), and low calcium hardness water source (See Appendix A.) The Langelier Index calculated for this water source on 17 September 1993 averaged -2.0 (Appendix C). Negative values for the Langelier Index indicate the water is carbonate scale dissolving at the supply temperatures, and a protective coating of precipitate is probably non-existent in the Base distribution system.

Soft, low-mineralized waters (such as the Lake Crescent water) are typically identified as the most corrosive to galvanized iron, black iron, and copper piping.

Lead piping (and lead from soldered joints) is also susceptible to lead leaching in this type of water. Residual free chlorine concentrations exceeding 0.4 mg/l may also increase corrosion (Reference for this paragraph (except added statements in parentheses): "Lead Control Strategies", page 226, American Water Works Association, 1990).

STEP 3 - DEFINE CONSTRAINTS

The LCR provides two conditions by which constraints may be considered in limiting the availability of alternative corrosion control treatments. These two conditions are: (1) options that adversely impact other water treatment processes and cause a violation of a National Primary Drinking Water Regulations; and (2) options that are otherwise ineffective for the water system.

The Base chlorinates the water removed from Lake Crescent and pipes it 10 miles to the Base. The National Primary Drinking Water Regulations constraints associated with pH/Alkalinity are outlined in Table 3-3a of the LCR Manual. These suggest that this method of treatment may reduce inactivation effectiveness of free chlorine if the pH/alkalinity treatment is applied before chlorination or if adequate chlorine contact time is not allowed before the pH is adjusted. Also, there may be selection and implementation impacts that would affect compliance with the Total Coliform Rule, in effect since 1991. Some water systems have experienced increases in distribution system microbiological growth after corrosion control treatment was initiated. However, in most cases no adverse impact has occurred. These considerations indicate that pH/alkalinity adjustments should not be practiced at the water treatment plant, but at some downstream point in the system before the treated water enters the distribution network.

The National Primary Drinking Water Regulations constraints associated with inhibitor treatments are outlined in Table 3-3b of the LCR Manual. These suggest that this method of treatment may result in depletion of disinfection residuals within the distribution system if there are existing corrosion byproducts. Also, if corrosion byproducts are released after the application of inhibitors, coliforms may be detected more frequently and confluent growth is more likely. Additionally, under some conditions, phosphate-based inhibitors may stimulate biofilms in the distribution system.

The following functional constraints should be considered in making a corrosion control treatment alternative selection:

- Inhibitor addition or pH/Alkalinity adjustment, if necessary, would occur at the water heating and storage area by Building 1400, the point-of-entry to the Base. This will involve a building at that location (existing buildings

may suffice), chemical delivery, daily operator attention, chemical storage, chemical feed controls and chemical feed equipment,

- sodium based chemicals must be evaluated as to their effect on the total sodium level in the drinking water,

- users with specific water quality needs, such as a hospital or a heating plant, must be advised of any changes in treatment,

- The use of inhibitors may result in complaints about red water, dirty water, color, and sediment within the distribution system,

STEP 4 - IDENTIFY CORROSION CONTROL PRIORITIES

As presented in previous sections of this report, lead is the priority element of concern for this corrosion control analysis. The 90th percentile of lead sampling results exceed the action level of 15 ppb, while the 90th percentile of copper sampling results were well below the action level of 1.3 mg/L in all but the initial round of sampling. Lead and copper levels were below detection limits at the Lake Crescent water source, ruling out the need for source water treatment. Therefore, the primary focus for complying with the LCR is corrosion control to reduce the leaching of lead from joints and fittings in the building interior piping.

Corrosion control treatment alternatives must inhibit the dissolution of lead without substantially increasing the dissolution of copper. None of the passivation techniques to be further considered in this Desktop Report are expected to have an adverse affect on copper dissolution.

STEP 5 - ELIMINATE UNSUITABLE APPROACHES

Precipitation of Calcium Carbonate

Since the source water is low in alkalinity, calcium, and pH, adjusting the pH alone to cause deposition of calcium carbonate throughout the Base water distribution system is not practical. Likewise, adding calcium to the source water to allow precipitation of calcium carbonate does not appear to have any merit since this would increase the need for local water softeners and may decrease the life expectancy for water heaters not supplied with softened water.

STEP 6 - EVALUATE VIABLE APPROACHES

Phosphate Inhibitors

Phosphate inhibitors function best in the pH range 7.4 to 7.8. Because the source water pH is below 7.4 (typical pH is 6.6 - temperature adjusted) and because addition of the acidic phosphate solutions would further lower the pH, the source water pH would have to be adjusted if this inhibitor were to be used. As stated in Step 3, raising the pH should not be practiced at the water treatment plant or negative impacts on disinfection effectiveness may occur. Because the source water is low in calcium and magnesium, little of the inhibitor would be lost to competing depletion mechanisms. However, the effectiveness of these type inhibitors is difficult to predict. The Base does have experience with phosphate-based inhibitors for corrosion protection of iron piping in the distribution system.

Also, as stated in Step 3, addition of inhibitors may have negative impacts on disinfection effectiveness and water acceptability due to poor color and/or turbidity. Furthermore, because the source water is poorly buffered, maintaining the proper pH throughout the distribution system may be difficult. As noted above, if the pH varies outside the range 7.4 to 7.8, inhibitor effectiveness diminishes rapidly.

Silicate Inhibitors

Silicate inhibitors are effective over a much broader pH range than phosphate inhibitors. This is a distinct advantage because pH throughout the distribution system may vary due to natural variations in the water temperature. Furthermore, as discussed below, controlling the pH using chemical additives would be difficult. Like the phosphate-base inhibitors, little of the silicate inhibitor would be lost to competing depletion mechanisms.

The effectiveness of silicate inhibitors is difficult to predict. Corrosion control appears to be a combination of adsorption and formation of less soluble metal-silicate compounds by combining with free metal released at the anode site of corrosion. A slightly corroded surface may be necessary to form the protective silicate film. The addition of silicate inhibitors to systems with extensive corrosion byproduct buildup may result in their release, causing red and turbid water problems.

Alkalinity and/or pH Adjustment

Figure 3-2 of the LCR Manual shows that minimum lead solubility occurs at a pH of about 9.8 and an alkalinity of 20 to 50 mg/L. Similar conditions provide minimum copper solubility. The source water is already low in alkalinity (~20mg/L) but has a low pH ($\leq$ 7). If the pH were raised without any significant increase in alkalinity, theoretical lead and copper concentrations would decrease in direct relation

to the increase in pH. Theoretical lead concentrations would decrease even further if the alkalinity were raised into the 30 to 50 mg/L range. The Langlier Index is near zero at a pH of 9.8 and alkalinity of 20 mg/l. The calcium carbonate precipitation potential is still quite negative at these conditions, indicating that calcium carbonate precipitation would not occur in the water distribution lines.

These considerations indicate that caustic soda (NaOH) would be the preferred chemical for pH adjustment. Caustic soda would convert any dissolved carbon dioxide to alkalinity; thus, some increase in alkalinity can be expected. Sodium bicarbonate and sodium carbonate would also increase the alkalinity with only little to moderate increase in the pH.

Because the Lake water is poorly buffered, pH control would be expected to be quite sensitive to the added caustic. Caustic would have to be added with good agitation and the addition be controlled with a pH (temperature adjusted) feedback loop. Even then, it is likely that pH would vary throughout the distribution system due to natural variations in the water temperature and chemical reactions with the pipe materials. Note that temperature variations and chemical reactions are most likely to occur in the indoor piping systems. This is the probable location where most of the corrosion is occurring.

STEP 7 - RECOMMEND OPTIMAL TREATMENT

Clearly, the choice of corrosion control method is either pH adjustment or silicate based inhibitor. The potential for poor pH control in critical parts of the distribution system and the effectiveness of silicate inhibitors over a wide pH range indicate that silicate inhibitors are the best alternative for reducing lead levels.

Silicate inhibitors are manufactured by fusing silica sands with a sodium or potassium salt. Sodium silicates are generally more common with sodium carbonate as the bonding salt. The sodium content of the water will increase slightly with sodium silicate addition. These generally have a silica to sodium carbonate molar ratio between 1.5 and 4. The most common form of silicate in water treatment is the 3.22 weight ratio sodium silicates at 41 °Baume' solution with 37 to 38 percent solids (Type N)[1]. Because the supply water typically has a low pH (temperature corrected), a more alkaline product should be considered to reduce acidity and increase the buffering capacity of the water. One such product is the 2.0 weight ratio SiO_2/Na_2O with 50.5 °Baume' solution (Type D)[1]. These products are in water solution, making handling and feeding convenient as well as amenable to automatic control and preclude the need for extensive tankage and equipment.

[1]Registered trademarks of The PQ Corporation, Philadelphia, PA.

According to The PQ Corporation, relatively high dosages of silicate are required during the first 30 to 60 days of treatment, in order to form the initial protective coating. This initial silicate dosage is referred to as a passivation dosage, and should be 24 mg/L above the background silica level.

The actual amount of time required to establish the initial coating will depend on the amount of silicate injected, water quality, water flow rates, and system length.

After the first 30 to 60 days of treatment, or once film formation has been verified, the dosage can be reduced to a maintenance dose. It is advisable to reduce the silica dose incrementally and perform silica balances over the system as the dosage is decreased, in order to verify the protective film remains intact. See Table 1 for a summary of sodium silicate usage for corrosion control.

Assuming that the daily water usage at Thule AB averages 100,000 gallons per day, 2 gallons of the 2.0 weight ratio product (Type D) will be needed each day to maintain a silica concentration of about 8 mg/L[2]. On an annual basis, 14-55 gallon drums of the inhibitor are required at the maintenance dosage of 8 mg/L. The annual cost for the sodium silicate is estimated to be $7,700 at a $10/gallon delivered price to the port of New York.

Two metering pumps, one on-line and one standby, piping and valves, and instrumentation would also be necessary to automate feeding of the inhibitor into the distribution system near Building 1400. Safety equipment is necessary to handle the chemical and an eyewash shower must be next to the chemical area.

The feed pumps should be located in a heated structure with water, sewer, and electrical service that is situated close to the storage tanks by Building 1400. Water temperature must be at least 40°F and preferably 50°F for effective chemical feed. Jar testing is necessary to establish the pH profile for the sodium silicate.

Addition of silicate inhibitor at the water plant next to Lake Crescent is not recommended as this may negatively impact disinfection effectiveness. The chemical feed equipment, piping and valves, instrumentation, mixing tank, safety equipment, and related items is estimated to cost approximately $30,000 for materials (stateside costs). This does not include the cost of a building if adequate space is not available in an existing facility close to Building 1400.

An EPA seminar publication, "Control of Lead and Copper in Drinking Water" (EPA/625/R-93/001) May 1993, provides information on the use of sodium silicate to control corrosion in a low alkalinity water in York, Maine. The methodology of usage, the findings from full scale application, and recommendations for usage are noted in the article (Appendix D).

[2]2.25 gallons of Type D SiO_2 will maintain a 1mg/L dosage in 1MG of water.

TABLE 1 SUMMARY TABLE FOR SODIUM SILICATE CORROSION CONTROL[3]	
1.	Silicates are approved as direct additives to potable water. They are nonhazardous, nontoxic, and nonflammable. They do not impart any taste or odor to water.
2.	American Water Works Association Standard for Liquid Sodium Silicate (ANSI/AWWA B404) reviews the use of sodium silicate in water treatment.
3.	The U.S. Environmental Protection Agency recognized that silicates may be effective in controlling lead and copper corrosion in potable water systems.
4.	At the dilutions typical in water treatment, most of the added silica is in the monomeric form.
5.	The silica in sodium silicate solutions carries a negative charge and will migrate to anodic areas, where it can react with metallic ions and form a protective film, which will inhibit corrosion.
6.	The sodium oxide present in silicate will typically raise pH. Increases in pH generally lead to decreased corrosion rates.
7.	The film does not build on itself and will not obstruct water flow.
8.	In areas of low water flow the supply of silica may eventually be exhausted within the effective range of the electrical forces around the anode. A sufficient water flow is required to supply additional silica.
9.	In areas of low flow, the pH contribution of the silicate may also be reduced.
10.	If only part of the area is protected, the remainder takes all the attack of the corrosive medium. Therefore it is important to use enough inhibitor.
11.	The efficacy of the silicate treatment may vary with the type of metal.
12.	The treatment has checked corrosion in systems where two dissimilar metals are in contact.
13.	A passivation dose of 24 mg SiO_2/L is recommended during the first 30-60 days of treatment, in order to quickly establish the protective film.
14.	After the protective film has been formed, it can be maintained by feeding less silicate. The optimum silicate dosage will depend on specific water chemistry and system characteristics.In most waters a maintenance dosage of 8 mg SiO_2/L is effective.

[3]Based on information from The PQ Corporation.

SUMMARY

This Desktop Report followed the seven steps described in the LCR Manual. Based on water quality at the point-of-entry, existing conditions in the Base distribution system, constraints and other conditions which eliminated unsuitable approaches, and an evaluation of the remaining viable alternatives, an optimal corrosion control treatment was recommended. Addition of a silica based inhibitor is the recommended method.

The chemicals, chemical handling equipment, and safety equipment must be housed in a heated structure supplied with utilities. This structure should be located close to Building 1400 where the potable water enters the Base distribution system.

The selected corrosion control treatment should perform satisfactorily, provide consistent and continuous protection, and be easily implemented.

APPENDIX A

Destktop Evaluation Short Form for Small and Medium PWS Treatment Recommendations

A. *PWS General Information:*

1. PWS Identification No. ____________________
2. Contact Person:
   - Name ____________________
   - Mailing Address ____________________
   - Telephone ____________ Fax ____________
3. Population served ____________
4. Person responsible for preparing this form:
   - Name ____________________
   - Signature ____________________
   - Telephone ____________

B. *PWS Technical Information:*

1. Monitoring Results:

Sampling dates: From ____________ To ____________

First Flush Tap Monitoring Results:

Lead:

Minimum Concentration	=	______ mg/L
Maximum Concentration	=	______ mg/L
90th percentile	=	______ mg/L

Copper:

Minimum Concentration	=	______ mg/L
Maximum Concentration	=	______ mg/L
90th percentile	=	______ mg/L

Point-of-Entry Tap Monitoring Results:

	Points of Entry				
	1	2	3	4	5
Lead Concentration in mg/L:	<0.1				
Copper Concentration in mg/L:	<0.001				
pH:	6.6				
Temperature, °C:	2				
Alkalinity, mg/L as $CaCO_3$:	20				
Calcium, mg/L as Ca:	6.4				
Conductivity, µmho/cm@25°C:	90				
Phosphate, mg/L as P:					
Silicate, mg/L as SiO_2:					

1. Monitoring Results (*continued*):

Water Quality Parameter Distribution System Monitoring Results:

Indicate whether field or laboratory measurement.

		Field	Lab
pH: miniumum = ______	maximum = ______	______	______
alkalinity:		______	______
minimum = ______	mg/L as $CaCO_3$		
maximum = ______	mg/L as $CaCO_3$		
temperature:		______	______
minimum = ______	°C		
maximum = ______	°C		
calcium:		______	______
minimum = ______	mg/L as Ca		
maximum = ______	mg/L as Ca		
conductivity:		______	______
minimum = ______	µmho/cm @ 25°C		
maximum = ______	µmho/cm @ 25°C		
orthophosphate: (if phosphate-based inhibitor is used)		______	______
minimum = ______	mg/L as P		
maximum = ______	mg/L as P		
silica: (if silica-based inhibitor is used)		______	______
minimum = ______	mg/L as SiO_2		
maximum = ______	mg/L as SiO_2		

2. Existing Conditions:

Is treatment used? yes ______ no X

Identify water source(s):

Source No. 1 Lake Crescent

Source No. 2 ______

Source No. 3 ______

If treatment is used, is more than one source used at a time?

yes ______ no ______

Identify treatment processes used for each source:

Process	No. 1	No. 2	No. 3
Presedimentation	No		
Aeration	No		
Chemical mixing	No		
Flocculation	No		
Sedimentation	No		
Recarbonation	No		

2. Existing Conditions (*continued*):

Identify treatment processes used for each source:

Process	No. 1	No. 2	No. 3
2nd Stage mixing			
2nd Stage flocculation			
2nd Stage sedimentation			
Filtration:			
Single medium			
Dual media			
Multi-media	Yes		
GAC cap on filters	Yes		
Disinfection:			
Chlorine	Yes		
Chlorine dioxide			
Chloramines			
Ozone	No		
Granular Activated Carbon			

List chemicals normally fed:

List chemicals sometimes fed:

3. Present Corrosion Control Treatment:

None X - Phosphate used in Segment J (iron pipe)

Inhibitor ______

Date initiated ______________

Present dose ______________

Range in Residual in Distribution System:

Maximum _________ mg/L Minimum _________ mg/L

Brand name ______________________________

Type ______________________________

Has it been effective? Please comment on your experience.

pH/alkalinity adjustment _________

pH Target _________

Alkalinity Target _________ mg/L $CaCO_3$

Calcium adjustment _________

Calcium Target _________ mg/L $CaCO_3$

4. Water Quality

Complete the table below for typical untreated and treated water quality data. Copy this form as necessary for additional sources. Include data for each raw water source, if surface supplies are used, and finished water quality information (point of entry) from each treatment plant. If wells are used, water quality information from each well is acceptable but not necessary if several wells have similar data. For groundwater supplies, include a water quality summary from each wellfield or grouping of wells with similar quality.

Include available data for the following:

Parameter	Untreated Supply	Treated Water (point of entry)
pH, units	6.6	
Alkalinity, mg/L as $CaCO_3$	20	
Conductivity, µmho/cm @ 25°C	90	
Total dissolved solids, mg/L		
Calcium, mg/L Ca	6.4	
Hardness, mg/L as $CaCO_3$	35	
Temperature, °C	2 degrees C	
Chloride, mg/L		
Sulfate, mg.L		

5. Distribution System:

Does the distribution system contain lead service lines?

Yes______ No_X___

If your system has lead service lines, mark below the approximate number of lines which can be located from existing records.

None____ Some____ Most____ All____

Is the distribution system flushed?

None_X_ Some____ Most____ All____

6. Historical Information

Is there a history of water quality complaints?
yes____ no_X__

If yes, then answer the following:
Are the complaints documented? yes____ no____

Mark the general category of complaints below. Use:
1 for some complaints in this category
2 for several complaints in this category
3 for severe complaints in this category

Categories of complaints:
Taste and odor ____
Color ____
Sediment ____
Other (specify) ____

Have there been any corrosion control studies?
yes____ no_X__

If yes, please indicate:
Date(s) of study From__________ To__________
Study conducted by PWS personnel? yes____ no____
Brief results of study were:

(Optional) Study results attached yes____ no____

Were treatment changes recommended? yes____ no____

If yes:
Were treatment changes implemented? yes____ no____
Have corrosion characteristics of the treated water changed? yes____ no____
If yes, how has change been measured?
General observation ______
Coupons ______
Frequency of complaints ______
Other ______

Briefly indicate, if other:

7. Treatment Constraints:

Optimal corrosion control treatment means the corrosion control treatment that minimizes the lead and copper concentrations at users' taps while insuring that the treatment does not cause the water system to violate any national primary drinking water regulations. Please indicate below which constraints to treatment will apply to your PWS. Use the following code:

1 Some constraint = Potential Impact but Extent is Uncertain
2 Significant constraint = Other Treatment Modifications Required to Operate Option
3 Severe constraint = Additional Capital Improvements Required to Operate Option
4 Very severe constraint = Renders Option Infeasible

Constraint	Treatments			
	pH/Alkalinity Adjustment	Calcium Adjustment	Inhibitor	
			PO_4	Si
A. Regulatory				
SOCs/IOCs				
SWTR: Turbidity				
Total Coliforms	1		1	
SWTR/GWDR: Disinfection	1		1	
Disinfection Byproducts				
Lead and Copper Rule				
Radionuclides				
B. Functional				
Taste & Odor				
Wastewater Permit				
Aesthetics				
Operational			1	1
Other		4		

8. **Desktop Evaluation**
Briefly summarize the review of the corrosion control literature that pertains to your PWS. A report or summary can be appended to this form if preferred.

LCR Guidance Manual,

- EPA Seminar Publication; "Control of Lead and Copper in Drinking Water"
- Information from The PQ Corporation

Were other similar facilities located which are experiencing successful corrosion control?

yes_X___ no____

If yes, identify their corrosion control treatment method.

None ____
pH/Alkalinity adjustment ____
Calcium adjustment ____
Inhibitor ____
Phosphate based ____
Silica based _X_

9. **Recommendations**

The corrosion control treatment method being proposed is:

pH/Alkalinity adjustment ______
Target pH is _____ units
Target alkalinity is _____ mg/L as $CaCO_3$
Calcium adjustment ______
Target calcium concentration is _____ mg/L Ca
Inhibitor ______
Phosphate based _____
Brand Name__________
Target Dose______ mg/L
Target residual _____ mg/L orthophosphate as p
Silica based _X_
Brand Name_Type D Sodium Silicate_
Target Dose__8__ mg/L
Target residual _____ mg/L as SiO_2

Rationale for the proposed corrosion control treatment is:

Discussed in the enclosed report_X_
Briefly explained below____

List your proposed operating guidelines:

Parameter	Operating Range
pH	8.0 (Temperature Corrected to 25° C)
SiO_2 (passivation)	24 mg/L
SiO_2 (maintenance)	8 mg/L

Briefly explain why these guidelines were selected.

Recommended by chemical producer

10. Please provide any additional comments that will assist in determining optimal corrosion control treatment for your PWS.

Table 3-6. Checklist for PWS Desk-Top Evaluations

I. Historical Evidence Review:

Did your utility:

	YES	NO
a. Determine Initial Water Quality	X	
WQP-POE and WQP-DIS	X	
Pb/Cu-POE	X	
Lead Solubility	X	
Copper Solubility	X	
CCPP Index Value		X
b. Conduct Prior Corrosion Control Investigations		X
c. Assess Corrosion Activity in the Distribution System for:		
Lead and Copper		X
Iron		X
A/C Pipe		X
Other Materials, please specify ________		X
d. Review the Literature	X	
e. Identify Comparable PWS Experience with Corrosion Control Treatment	X	

(If YES, what was the overall performance of the alternative treatment approaches)

	Very Good	Good	Poor	Adverse
pH/Alkalinity Adjustment				
Calcium Adjustment				
Corrosion Inhibitors				
Phosphates				
Silicates		X		

f. Source Water Treatment Status

Required	
Recommended	
Optional	
Not Necessary	X

Table 3-6. Checklist for PWS Desk-Top Evaluations (continued)

g. Based on your water quality characteristics, check the suggested treatment approach(es) per Figure 3-7 in Volume II of the Guidance Manual.

pH/Alkalinity Adjustment	X
Calcium Adjustment	
Corrosion Inhibitors	
Phosphates	X
Silicates	X

II. Constraint Definitions

Is the constraint identified applicable to your system? (Based on Rankings of 3 or 4 on Form 141-C)

	YES	NO
Regulatory Constraints:		
SOCs/IOCs		X
SWTR: Turbidity		X
Total Coliforms	X	
SWTR/GWTR: Disinfection	X	
D/DBPs	X	
LCR		X
Radionuclides		X
Functional Constraints:		
Taste and Odor		X
Wastewater Permit		X
Aesthetics	X	
Operational		X
Other		X

III. Were any treatment approaches eliminated from further consideration in the desk-top evaluation?

	YES	NO
pH/Alkalinity Adjustment		X
Calcium Adjustment	X	
Corrosion Inhibitors:		X
Phosphates		X
Zinc Orthophosphate		
Sodium Orthophosphate		
__________ Orthophosphate		
Poly-ortho-phosphates		
Polyphosphates		
Silicates		X

Table 3-6. Checklist for PWS Desk-Top Evaluations (continued)

IV. For each of the feasible treatment alternatives, did your system evaluate the following in the desk-top evaluation?

	YES	NO
Performance	X	
Feasibility	X	
Reliability	X	
Costs	X	

V. What is the recommended treatment approach?

	YES	NO
Source Water Treatment:		X

Method, specify:

____

____

	YES	NO
Corrosion Control Treatment	X	
pH/Alkalinity Adjustment		X
Calcium Adjustment		X
Corrosion Inhibitors:		
Phosphates		X

Specify type:

____

____

	YES	NO
Silicates	X	

Specify type:

____

____

Acc 18

Charecteristics Sampling

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930084

Source: LAKE Crescent Supply

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: PS001 DATE RECEIVED: 931126

DATE COLLECTED: 931117 DATE REPORTED: 931206

SAMPLE SUBMITTED BY: 12 FWS/SGB

PRESERVATION GROUP G OEHD SAMPLE #: 93058131 ANALYSIS DATE: 931203

Test	Results	Units	Method
Alkalinity (total)	20	mg/L	EPA 310.2
Langelier Index	-3.25		STD METH 203
Residue, filterable	66	mg/L	EPA 160.1
pH	6.5		
Temp	2°C		

Memo for Record 7 JAN 93

These are results of Drinking water charecteristics due to Thule AFB Exceeding standards for the copper and lead rule. Peterson AFB Bioenvironmental Engineering section has been given a copy of this report. Awaiting word on firming up funds to pay for the water study contractors (PES, Pacific environmental services) from Lt Col. Martin at 21 MG/SGPB, PAFB, CO.

TSGT Saxyard

Reviewed by:

Wanda Salmon

Duryl S. Bird, GS-12
Chief, Inorganic Analysis Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

Tice 18

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930085 OEHL SAMPLE NO: 93058132

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: PS001 DATE RECEIVED: 931126

DATE COLLECTED: 931117 DATE REPORTED: 940118

DATE ANALYZED: 931214

SAMPLE SUBMITTED BY: 12 FWS/SGB

RESULTS

Test	Results	Units	Method
Calcium	6.4	mg/L	EPA 200.7
Magnesium	5.0	mg/L	EPA 200.7
Hardness	37	mg/L	EPA 200.7
pH	6.6		
Temp	2°C		

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

Summer

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

Cu & Pb

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930041 OEHL SAMPLE NO: 93039755

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX097 DATE RECEIVED: 930809

DATE COLLECTED: 930730 DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 97

RESULTS

Test	Results	Units	Method
Copper	1.5	mg/L	EPA 200.7
Lead	0.003	mg/L	EPA 239.2

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930042   OEHL SAMPLE NO: 93039756

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX105   DATE RECEIVED: 930809

DATE COLLECTED: 930730   DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 105   RESULTS

Test	Results	Units	Method
Copper	2.1	mg/L	EPA 200.7
Lead	0.067	mg/L	EPA 239.2

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930043 OEHL SAMPLE NO: 93039757

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX107 DATE RECEIVED: 930809

DATE COLLECTED: 930730 DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 107 RESULTS

Test	Results	Units	Method
Copper	<0.1	mg/L	EPA 200.7
Lead	0.001	mg/L	EPA 239.2

Comments:

< - Signifies none detected and the detection limits.

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930044 OEHL SAMPLE NO: 93039758

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX115 DATE RECEIVED: 930809

DATE COLLECTED: 930730 DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 115

RESULTS

Test	Results	Units	Method
Copper	0.8	mg/L	EPA 200.7
Lead	0.003	mg/L	EPA 239.2

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930046 OEHL SAMPLE NO: 93039760

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX236 DATE RECEIVED: 930809

DATE COLLECTED: 930730 DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 126

RESULTS

Test	Results	Units	Method
Copper	0.8	mg/L	EPA 200.7
Lead	0.051	mg/L	EPA 239.2

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930045 OEHL SAMPLE NO: 93039759

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX127 DATE RECEIVED: 930809

DATE COLLECTED: 930730 DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 127

RESULTS

Test	Results	Units	Method
Copper	1.5	mg/L	EPA 200.7
Lead	0.001	mg/L	EPA 239.2

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930047 OEHL SAMPLE NO: 93039761

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX334 DATE RECEIVED: 930809

DATE COLLECTED: 930730 DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 334

RESULTS

Test	Results	Units	Method
Copper	0.2	mg/L	EPA 200.7
Lead	0.004	mg/L	EPA 239.2

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930048 OEHL SAMPLE NO: 93039762

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX362 DATE RECEIVED: 930809

DATE COLLECTED: 930730 DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 362

RESULTS

Test	Results	Units	Method
Copper	0.7	mg/L	EPA 200.7
Lead	0.006	mg/L	EPA 239.2

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930049

OEHL SAMPLE NO: 93039763

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX367

DATE COLLECTED: 930730

DATE RECEIVED: 930809

DATE ANALYZED: 930831

DATE REPORTED: 930910

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 367

RESULTS

Test	Results	Units	Method
Copper	0.9	mg/L	EPA 200.7
Lead	0.072	mg/L	EPA 239.2

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930050 — OEHL SAMPLE NO: 93039764

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX608 — DATE RECEIVED: 930809

DATE COLLECTED: 930730 — DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 608

RESULTS

Test	Results	Units	Method
Copper	0.2	mg/L	EPA 200.7
Lead	0.006	mg/L	EPA 239.2

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930051 OEHL SAMPLE NO: 93039765

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX707 DATE RECEIVED: 930809

DATE COLLECTED: 930730 DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 707

RESULTS

Test	Results	Units	Method
Copper	0.6	mg/L	EPA 200.7
Lead	0.021	mg/L	EPA 239.2

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930052 OEHL SAMPLE NO: 93039766

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX708 DATE RECEIVED: 930809

DATE COLLECTED: 930730 DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 708

RESULTS

Test	Results	Units	Method
Copper	0.4	mg/L	EPA 200.7
Lead	0.007	mg/L	EPA 239.2

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

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APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930053 OEHL SAMPLE NO: 93039767

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX750 DATE RECEIVED: 930809

DATE COLLECTED: 930730 DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 750

RESULTS

Test	Results	Units	Method
Copper	0.9	mg/L	EPA 200.7
Lead	0.018	mg/L	EPA 239.2

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930054 OEHL SAMPLE NO: 93039768

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX760 DATE RECEIVED: 930809

DATE COLLECTED: 930730 DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 760

RESULTS

Test	Results	Units	Method
Copper	0.2	mg/L	EPA 200.7
Lead	0.016	mg/L	EPA 239.2

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930055 OEHL SAMPLE NO: 93039769

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX837 DATE RECEIVED: 930809

DATE COLLECTED: 930730 DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 837

RESULTS

Test	Results	Units	Method
Copper	<0.1	mg/L	EPA 200.7
Lead	<0.001	mg/L	EPA 239.2

Comments:

< - Signifies none detected and the detection limits.

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930056 OEHL SAMPLE NO: 93039770

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XX014 DATE RECEIVED: 930809

DATE COLLECTED: 930730 DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

BLDG 1400 RESULTS

Test	Results	Units	Method
Copper	0.2	mg/L	EPA 200.7
Lead	0.010	mg/L	EPA 239.2

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP930057 OEHL SAMPLE NO: 93039771

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 930809

DATE COLLECTED: 930730 DATE REPORTED: 930910

DATE ANALYZED: 930831

SAMPLE SUBMITTED BY: 12 FWS/SGB

---

crescent Lake RESULTS

Test	Results	Units	Method
Copper	<0.1	mg/L	EPA 200.7
Lead	<0.001	mg/L	EPA 239.2

Comments:

< - Signifies none detected and the detection limits.

Reviewed by: Leo J. Jehl Jr.
Chemist, GS-13
Special Projects Function

TO:

12 FWS/SGB

APO AE 09704-5000

WINTER

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

– Cu & Pb

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940109

OEHL SAMPLE NO: 94005229

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX

DATE RECEIVED: 940211

DATE COLLECTED: 940202

DATE REPORTED: 940217

DATE ANALYZED: 940216

97

RESULTS

Test	Results	Units	Method
Copper	0.08	mg/L	EPA 220.1
Lead	0.011	mg/L	EPA 239.2

Comments:

PBCU

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940108 OEHL SAMPLE NO: 94005228

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

107

RESULTS

Test	Results	Units	Method
Copper	<0.02	mg/L	EPA 220.1
Lead	<0.001	mg/L	EPA 239.2

Comments:

PBCU
< - Signifies none detected and the detection limits.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940107 OEHL SAMPLE NO: 94005227

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

115

RESULTS

Test	Results	Units	Method
Copper	0.05	mg/L	EPA 220.1
Lead	<0.001	mg/L	EPA 239.2

Comments:

PBCU
< - Signifies none detected and the detection limits.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940106 OEHL SAMPLE NO: 94005226

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

127

RESULTS

Test	Results	Units	Method
Copper	0.28	mg/L	EPA 220.1
Lead	<0.001	mg/L	EPA 239.2

Comments:

PBCU
< - Signifies none detected and the detection limits.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940101 OEHL SAMPLE NO: 94005221

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

245

RESULTS

Test	Results	Units	Method
Copper	0.25	mg/L	EPA 220.1
Lead	0.018	mg/L	EPA 239.2

Comments:

PBCU
LEAD EXCEEDS MCL OF 0.015 MG/L PER EPA REGULATION.
DUPLICATE ANALYSIS PERFORMED.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940100 OEHL SAMPLE NO: 94005220

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

256 RESULTS

Test	Results	Units	Method
Copper	0.12	mg/L	EPA 220.1
Lead	<0.001	mg/L	EPA 239.2

Comments:

PBCU
< - Signifies none detected and the detection limits.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940102 OEHL SAMPLE NO: 94005222

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

325

RESULTS

Test	Results	Units	Method
Copper	0.08	mg/L	EPA 220.1
Lead	<0.001	mg/L	EPA 239.2

Comments:

PBCU
< - Signifies none detected and the detection limits.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940113 OEHL SAMPLE NO: 94006423

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940218

DATE COLLECTED: 940201 DATE REPORTED: 940415

DATE ANALYZED: 940413

---

426 RESULTS

Test	Results	Units	Method
Copper	0.027	mg/L	EPA 220.1
Lead	<0.001	mg/L	EPA 239.2

Comments:

< - Signifies none detected and the detection limits.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940097 OEHL SAMPLE NO: 94005217

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

463

RESULTS

Test	Results	Units	Method
Copper	0.15	mg/L	EPA 220.1
Lead	0.018	mg/L	EPA 239.2

Comments:

PBCU
LEAD EXCEEDS MCL OF 0.015 MG/L PER EPA REGULATION.
DUPLICATE ANALYSIS PERFORMED.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940095 OEHL SAMPLE NO: 94005215

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

RESULTS

580

Test	Results	Units	Method
Copper	0.04	mg/L	EPA 220.1
Lead	0.002	mg/L	EPA 239.2

Comments:

PBCU

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940104 OEHL SAMPLE NO: 94005224

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

608

RESULTS

Test	Results	Units	Method
Copper	0.03	mg/L	EPA 220.1
Lead	<0.001	mg/L	EPA 239.2

Comments:

PBCU
< - Signifies none detected and the detection limits.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940110 OEHL SAMPLE NO: 94005230

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

619

RESULTS

Test	Results	Units	Method
Copper	<0.02	mg/L	EPA 220.1
Lead	<0.001	mg/L	EPA 239.2

Comments:

PBCU
< - Signifies none detected and the detection limits.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940111 OEHL SAMPLE NO: 94005231

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

630

RESULTS

Test	Results	Units	Method
Copper	0.05	mg/L	EPA 220.1
Lead	0.011	mg/L	EPA 239.2

Comments:

PBCU

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940099 OEHL SAMPLE NO: 94005219

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

707 RESULTS

Test	Results	Units	Method
Copper	0.06	mg/L	EPA 220.1
Lead	0.007	mg/L	EPA 239.2

Comments:

PBCU

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940103   OEHL SAMPLE NO: 94005223

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX   DATE RECEIVED: 940211

DATE COLLECTED: 940202   DATE REPORTED: 940217

DATE ANALYZED: 940216

708

RESULTS

Test	Results	Units	Method
Copper	0.02	mg/L	EPA 220.1
Lead	0.003	mg/L	EPA 239.2

Comments:

PBCU

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940096 OEHL SAMPLE NO: 94005216

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

---

750 RESULTS

Test	Results	Units	Method
Copper	0.03	mg/L	EPA 220.1
Lead	0.002	mg/L	EPA 239.2

Comments:

PBCU

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940105 OEHL SAMPLE NO: 94005225

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

760

RESULTS

Test	Results	Units	Method
Copper	0.09	mg/L	EPA 220.1
Lead	0.018	mg/L	EPA 239.2

Comments:

PBCU
LEAD EXCEED MCL OF 0.015 MG/L PER EPA REGULATION.
DUPLICATE ANALYSIS PERFORMED.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940098 OEHL SAMPLE NO: 94005218

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

774 RESULTS

Test	Results	Units	Method
Copper	0.64	mg/L	EPA 220.1
Lead	0.018	mg/L	EPA 239.2

Comments:

PBCU
LEAD EXCEEDS MCL OF 0.015 MG/L PER EPA REGULATION.
DUPLICATE ANALYSIS PERFORMED.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114 -

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940093 OEHL SAMPLE NO: 94005213

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

801

RESULTS

Test	Results	Units	Method
Copper	0.22	mg/L	EPA 220.1
Lead	0.022	mg/L	EPA 239.2

Comments:

PBCU
LEAD EXCEEDS MCL OF 0.015 MG/L PER EPA REGULATION.
DUPLICATE ANALYSIS PERFORMED.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPURT OF ANALYSIS

BASE SAMPLE NO: GP940094 OEHL SAMPLE NO: 94005214

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

836 RESULTS

Test	Results	Units	Method
Copper	0.04	mg/L	EPA 220.1
Lead	0.003	mg/L	EPA 239.2

Comments:

PBCU

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940092 OEHL SAMPLE NO: 94005212

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

935

RESULTS

Test	Results	Units	Method
Copper	0.02	mg/L	EPA 220.1
Lead	<0.001	mg/L	EPA 239.2

Comments:

PBCU
< - Signifies none detected and the detection limits.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940112 OEHL SAMPLE NO: 94005232

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

1400

RESULTS

Test	Results	Units	Method
Copper	<0.02	mg/L	EPA 220.1
Lead	0.018	mg/L	EPA 239.2

Comments:

PBCU
LEAD EXCEEDS MCL OF 0.015 MG/L PER EPA REGULATION.
DUPLICATE ANALYSIS PERFORMED.
< - Signifies none detected and the detection limits.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

AL/OEA
2402 E DRIVE
BROOKS AFB, TEXAS, 78235-5114

REPORT OF ANALYSIS

BASE SAMPLE NO: GP940114 OEHL SAMPLE NO: 94005233

SAMPLE TYPE: POTABLE WATER

SITE IDENTIFIER: XXXXX DATE RECEIVED: 940211

DATE COLLECTED: 940202 DATE REPORTED: 940217

DATE ANALYZED: 940216

LAKE Crescent RESULTS

Test	Results	Units	Method
Copper	<0.02	mg/L	EPA 220.1
Lead	<0.001	mg/L	EPA 239.2

Comments:

PBCU
< - Signifies none detected and the detection limits.

Reviewed by: Gerald R. Wittenbach
Chief, Environmental Metals Function

TO:

12 FWS/SGB

APO AE 09704-5000

GREENLAND CONTRACTORS
Thule Air Base
Environmental Engineering Group
Thyge Færch/amk

20 September 1994
GC/EEG
FY94-762

Total number of pages: 8

TELEFAX

Pacific Environmental Services, INC
560 Herndon Parkway, Suite 200
Herndon, VA 22070

Fax: (703) 481-8296

For Wayne Westbrook

Attn.: Robert Forbes

GC-121, Contract No. F61101-91-C-0003

Potable Water Survey Performed for USAF, 21 SPW Bioenvironmental Section.

Reference is made to our telephone conversation on 16 September, subject as above.

Enclosed please find:

- Sampling results from Lead and Copper non-compliance tests, July 1993 to July 1994. Note that the sampling locations were changed in order to better reflect the entire installation in February 1994.

- Saturation index was calculated for a sample, collected at the main entrance base potable water system, according to "Standard Methods for the Examination of Water and Wastewater", 17th edition 1989: 2330 Calcium Carbonate Saturation (Approved by Standard Methods Committee, 1989).

Please be informed that phosphate, in the raw water as well as in the treated water, is below our detection limit of 0.1 ppm. The temperature of the raw water has previously been reported to 21 SPW, Bioenvironmental Section.

In the event you should have any questions, or if further clarification is required, please do not hesitate to call the undersigned at + 299-50636 ext. 2698.

Sincerely,

Thyge Færch
Chief of EEG

c.c.: 12 SWS/LG

Thule Lead and Copper non-compliance tests
July 1993 July 1994

Lead tests: Action Level 0.015 mg/L as 90th percentile.
Detection limit for Lead is 0.001 mg/L, although results of 0.001 mg/L may contain less.

Fac.	Lead 07/93	Lead 02/94	Lead 07/94
0097	0.003	0.011	0.055
0107	0.001	0.001	0.001
0115	0.003	0.001	0.003
0127	0.001	0.001	0.001
0245		0.018	0.020
0256		0.001	0.001
0325		0.001	0.001
0463		0.018	0.022
0580		0.002	0.028
0608	0.006	0.001	0.002
0619		0.001	0.001
0630		0.011	0.002
0707		0.021	0.002
0708	0.007	0.003	0.016
0750	0.018	0.002	0.011
0760	0.016	0.018	0.012
0774		0.018	
0801	0.001	0.022	0.007
0836		0.003	0.012
0935		0.001	0.065
1400	0.010	0.018	0.010
Test result	0.051	0.018	0.028

Comment: Tests sampled 07/93 were collected at locations different from the samplings 02/94 and 07/94

Copper tests: Action Level 1.3 mg/L as 90th percentile.
Detection limit for Copper is 0.02 mg/L, although results of 0.02 mg/L may contain less, except for Bldg #935 where the specific result of 0.014 mg/L for some reason is given.

Fac.	Copper 0793	Copper 0294	Copper 0794
0097	1.5	0.08	0.12
0107	0.1	0.02	0.020
0115	0.8	0.05	0.08
0127	1.5	0.28	0.20
0245		0.25	0.23
0256		0.12	0.062
0325		0.08	0.064
0463		0.15	0.133
0580		0.04	0.062
0608	0.2	0.03	0.030
0619		0.02	0.020
0630		0.05	0.039
0707		0.6	0.032
0708	0.4	0.02	0.058
0750	0.9	0.03	0.020
0760	0.27	0.09	0.064
0774		0.64	
0801	0.1	0.22	0.158
0836		0.04	0.148
0935		0.02	0.014
1400	0.2	0.02	0.020
Test result	1.5	0.28	0.158

Comment: Tests sampled 07/93 were collected at locations different from the samplings of 02/94 and 07/94.

Thyge Færch,
12 september 1994

SATURATION INDEX

SAMPLE NUMBER: 1 **DATE:** 17 SEP 93

Measurements: Temperature : 9 °C
pH (temp adj.) : 6,6

	MÅLINGER	BEREGNINGER	
Conduktivity	90 umhos/cm=z	I= z*1,6*10^{5}	I= 1,44 · 10^{-3}
Calcium	30 ppm=x	X= x/40.1*10^{3}	-logX= 3,13 = p[Ca]
Alkalinity	16 ppm=y	Y= y/61,0*10^{3}	-logY= 3,58 =p[HCO_3]

TABLE 2330:II. PRECALCULATED VALUES FOR pK AND A AT SELECTED TEMPERATURES

Temperature °C	pK_2	pK_s Calcite	pK_s Aragonite	pK_s Vaterite	pK_w	A
5	10.55	8.39	8.24	7.77	14.73	0.494
10	10.49	8.41	8.26	7.80	14.53	0.498
15	10.43	8.43	8.28	7.84	14.34	0.502
20	10.38	8.45	8.31	7.87	14.16	0.506
25*	10.33	8.48	8.34	7.91	13.99	0.511
30	10.29	8.51	8.37	7.96	13.83	0.515
35	10.25	8.54	8.41	8.00	13.68	0.520
40	10.22	8.58	8.45	8.05	13.53	0.526
45	10.20	8.62	8.49	8.10	13.39	0.531
50	10.17	8.66	8.54	8.16	13.26	0.537
60	10.14	8.76	8.64	8.25	13.02	0.549
70	10.13	8.87	8.75	8.40	—	0.562
80	10.13	8.99	8.88	8.55	—	0.576
90	10.14	9.12	9.02	8.70	—	0.591

NOTE: All values determined from the equations of Table 2330:I.

pK_2= 10,50 pK_s= 8,41 (calcite) pK_w= 14,57 A = 0,497

$$pf_m = A \cdot \frac{\sqrt{I}}{1+\sqrt{I}} + (0.3 \cdot I) = 0,0177$$

$$pH_s = pK_2 \div pK_s + p[Ca] + p[HCO_3] + 5\ pf_m = 8,89$$

$$SI = pH \div pH_s = \quad = -2,3$$

SATURATION INDEX

SAMPLE NUMBER: 2 **DATE:** 17 SEP 93

Measurements: Temperature : 9 °C
pH (temp adj.) : 6.8

	MÅLINGER	BEREGNINGER	
Conduktivity	90 umhos/cm=z	I= z*1,6*10^{-5}	I= 1.44·10^{-3}
Calcium	35 ppm=x	X= x/40.1*10^3	-logX= 3,06 = p[Ca]
Alkalinity	18 ppm=y	Y= y/61,0*10^3	-logY= 3,53 =p[HCO_3]

TABLE 2330:II. PRECALCULATED VALUES FOR pK AND A AT SELECTED TEMPERATURES

Temperature °C	pK_2	pK_s Calcite	pK_s Aragonite	pK_s Vaterite	pK_w	A
5	10.55	8.39	8.24	7.77	14.73	0.494
10	10.49	8.41	8.26	7.80	14.53	0.498
15	10.43	8.43	8.28	7.84	14.34	0.502
20	10.38	8.45	8.31	7.87	14.16	0.506
25*	10.33	8.48	8.34	7.91	13.99	0.511
30	10.29	8.51	8.37	7.96	13.83	0.515
35	10.25	8.54	8.41	8.00	13.68	0.520
40	10.22	8.58	8.45	8.05	13.53	0.526
45	10.20	8.62	8.49	8.10	13.39	0.531
50	10.17	8.66	8.54	8.16	13.26	0.537
60	10.14	8.76	8.64	8.28	13.02	0.549
70	10.13	8.87	8.75	8.40	—	0.562
80	10.13	8.99	8.88	8.55	—	0.576
90	10.14	9.12	9.02	8.70	—	0.591

NOTE: All values determined from the equations of Table 2330:I.

pK_2= 10.50 pK_s= 8.41 (calcite) pK_w= 14.53 A = 0,497

$$pf_m = A \cdot \frac{\sqrt{I}}{1+\sqrt{I}} \div (0.3 \cdot I) = 0,0177$$

$$pH_s = pK_2 \div pK_s + p[Ca] + p[HCO_3] + 5\ pf_m = 8,77$$

$$SI = pH \div pH_s = \quad = -2,0$$

SATURATION INDEX

SAMPLE NUMBER: 3 **DATE:** 17 SEP 93

Measurements: Temperature : 9 °C
pH (temp adj.) : 6.9

	MÅLINGER	BEREGNINGER	
Conduktivity	90 umhos/cm=z	I= z*1,6*10^{-5}	I= 1.44·10^{-3}
Calcium	35 ppm=x	X= x/40.1*10^{3}	-logX= 3,06 = p[Ca]
Alkalinity	18 ppm=y	Y= y/61,0*10^{3}	-logY= 3,53=p[HCO_3]

TABLE 2330:II. PRECALCULATED VALUES FOR pK AND A AT SELECTED TEMPERATURES

Temperature °C	pK_2	pK_s Calcite	pK_s Aragonite	pK_s Vaterite	pK_w	A
5	10.55	8.39	8.24	7.77	14.73	0.494
10	10.49	8.41	8.26	7.80	14.53	0.498
15	10.43	8.43	8.28	7.84	14.34	0.502
20	10.38	8.45	8.31	7.87	14.16	0.506
25*	10.33	8.48	8.34	7.91	13.99	0.511
30	10.29	8.51	8.37	7.96	13.83	0.515
35	10.25	8.54	8.41	8.00	13.68	0.520
40	10.22	8.58	8.45	8.05	13.53	0.526
45	10.20	8.62	8.49	8.10	13.39	0.531
50	10.17	8.66	8.54	8.16	13.26	0.537
60	10.14	8.76	8.64	8.28	13.02	0.549
70	10.13	8.87	8.75	8.40	—	0.562
80	10.13	8.99	8.88	8.55	—	0.576
90	10.14	9.12	9.02	8.70	—	0.591

NOTE: All values determined from the equations of Table 2330:I.

pK_2= 10.50 pK_s= 8,41 (calcite) pK_w= 14,57 A = 0,497

$$pf_m = A \cdot \frac{\sqrt{I}}{1 + \sqrt{I}} \div (0.3 \cdot I) = 0,0177$$

$$pH_s = pK_2 + pK_s + p[Ca] + p[HCO_3] + 5\ pf_m = 8.77$$

$$SI = pH \div pH_s = \quad = -1.9$$

SATURATION INDEX

SAMPLE NUMBER: 4 **DATE:** 17 SEP 93

Measurements: Temperature : 9 °C
pH (temp adj.) : 6,9

	MÅLINGER	BEREGNINGER	
Conduktivity	90 umhos/cm=z	$I = z*1,6*10^{-5}$	$I = 1{,}44 \cdot 10^{-3}$
Calcium	35 ppm=x	$X = x/40.1*10^{3}$	$-\log X = 3{,}06 = p[Ca]$
Alkalinity	16 ppm=y	$Y = y/61{,}0*10^{3}$	$-\log Y = 3{,}58 = p[HCO_3]$

TABLE 2330:II. PRECALCULATED VALUES FOR pK AND A AT SELECTED TEMPERATURES

Temperature °C	pK_2	pK_s Calcite	pK_s Aragonite	pK_s Vaterite	pK_w	A
5	10.55	8.39	8.24	7.77	14.73	0.494
10	10.49	8.41	8.26	7.80	14.53	0.498
15	10.43	8.43	8.28	7.84	14.34	0.502
20	10.38	8.45	8.31	7.87	14.16	0.506
25*	10.33	8.48	8.34	7.91	13.99	0.511
30	10.29	8.51	8.37	7.96	13.83	0.515
35	10.25	8.54	8.41	8.00	13.68	0.520
40	10.22	8.58	8.45	8.05	13.53	0.526
45	10.20	8.62	8.49	8.10	13.39	0.531
50	10.17	8.66	8.54	8.16	13.26	0.537
60	10.14	8.76	8.64	8.28	13.02	0.549
70	10.13	8.87	8.75	8.40	—	0.562
80	10.13	8.99	8.88	8.55	—	0.576
90	10.14	9.12	9.02	8.70	—	0.591

NOTE: All values determined from the equations of Table 2330:I.

$pK_2 = 10{,}50$ $pK_s = 8{,}41$ (calcite) $pK_w = 14{,}53$ $A = 0{,}497$

$$pf_m = A \cdot \frac{\sqrt{I}}{1+\sqrt{I}} \div (0.3 \cdot I) = 0{,}0177$$

$$pH_s = pK_2 \div pK_s + p[Ca] + p[HCO_3] + 5\,pf_m = 8{,}82$$

$$SI = pH \div pH_s = \quad = -1{,}9$$

SATURATION INDEX

SAMPLE NUMBER: 5 DATE: 17 SEP 93

Measurements: Temperature : 9 °C
pH (temp adj.) : 6,9

	MÅLINGER	BEREGNINGER	
Conduktivity	90 umhos/cm=z	$I = z*1,6*10^{-5}$	$I = 1,44 \cdot 10^{-3}$
Calcium	35 ppm=x	$X = x/40.1*10^3$	-logX= 3,06 = p[Ca]
Alkalinity	16 ppm=y	$Y = y/61,0*10^3$	-logY= 3,58 = p[HCO_3]

TABLE 2330:II. PRECALCULATED VALUES FOR pK AND A AT SELECTED TEMPERATURES

Temperature °C	pK_2	pK_s Calcite	pK_s Aragonite	pK_s Vaterite	pK_w	A
5	10.55	8.39	8.24	7.77	14.73	0.494
10	10.49	8.41	8.26	7.80	14.53	0.498
15	10.43	8.43	8.28	7.84	14.34	0.502
20	10.38	8.45	8.31	7.87	14.16	0.506
25*	10.33	8.48	8.34	7.91	13.99	0.511
30	10.29	8.51	8.37	7.96	13.83	0.515
35	10.25	8.54	8.41	8.00	13.68	0.520
40	10.22	8.58	8.45	8.05	13.53	0.526
45	10.20	8.62	8.49	8.10	13.39	0.531
50	10.17	8.66	8.54	8.16	13.26	0.537
60	10.14	8.76	8.64	8.28	13.02	0.549
70	10.13	8.87	8.75	8.40	—	0.562
80	10.13	8.99	8.88	8.55	—	0.576
90	10.14	9.12	9.02	8.70	—	0.591

NOTE: All values determined from the equations of Table 2330:I.

pK_2 = 10,50 pK_s = 8,41 (calcite) pK_w = 14,57 A = 0,497

$$pf_m = A \cdot \frac{\sqrt{I}}{1 + \sqrt{I}} \div (0.3 \cdot I) = 0,0177$$

$$pH_s = pK_2 + pK_s + p[Ca] + p[HCO_3] + 5\ pf_m = 8,82$$

$$SI = pH \div pH_s = \quad = -1,9$$

APPENDIX D

United States
Environmental Protection
Agency

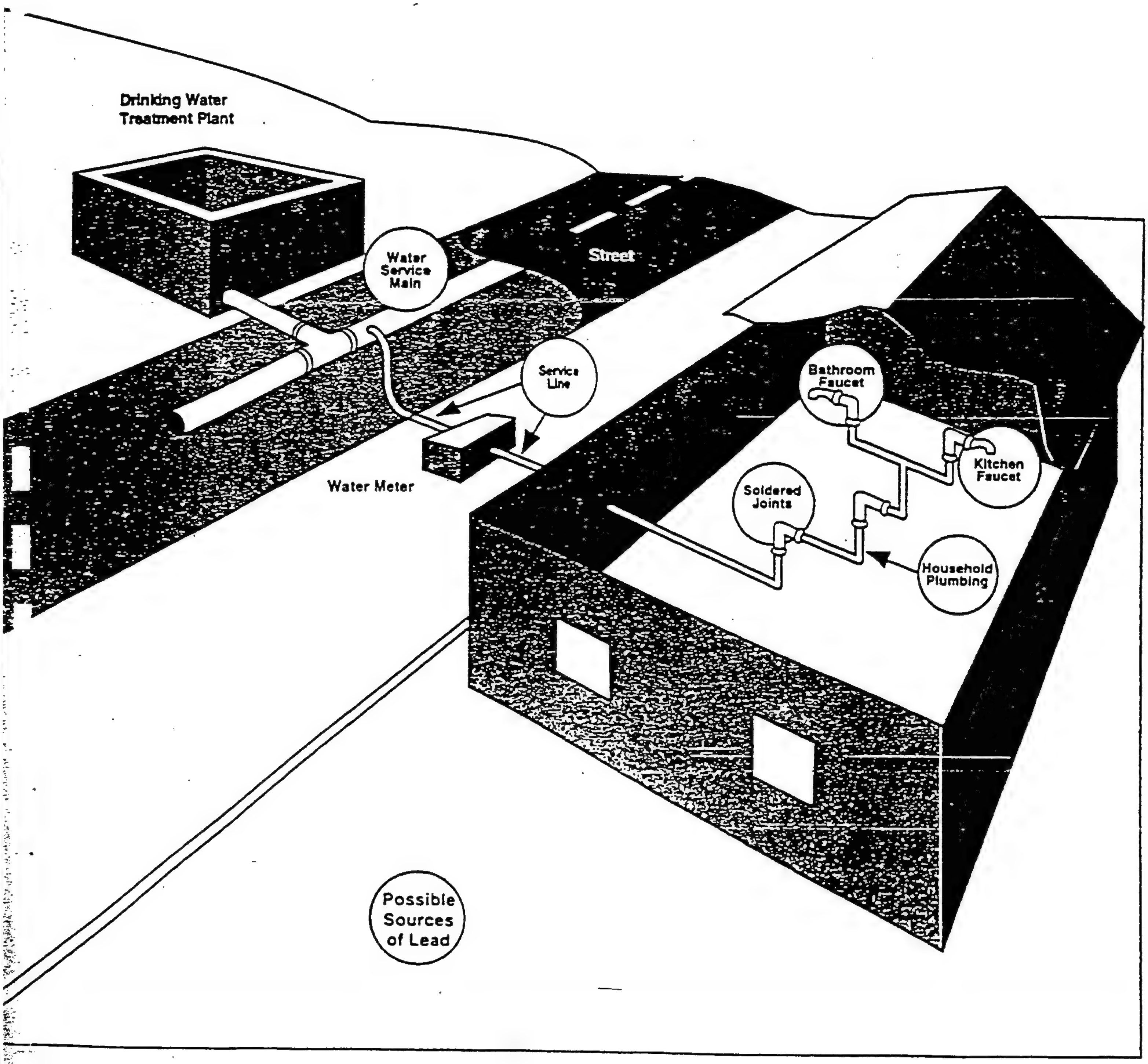
Office of Research and
Development
Washington, DC 20460

EPA/625/R-93/001
May 1993

EPA

Seminar Publication

Control of Lead and Copper in Drinking Water



5.3 Full-Scale Performance Testing of Sodium Silicate to Control the Corrosion of Lead, Copper, and Iron: York, Maine

5.3.1 Introduction

In Summer 1991, the York Water District (YWD) in Maine placed a 4 million gallons per day (mgd) water treatment facility into service to provide coagulation, clarification, filtration, and disinfection of its surface water supply. The plant was designed to meet the requirements of the SWTR. In common with other surface water treatment plants in New England, the water produced by the plant is soft (Ca <1 mg/L), low in alkalinity (<10 mg/L as $CaCO_3$), and has a moderately high pH (8.3 to 8.8). As this generally corrosive water passed through the distribution system, it picked up significant quantities of iron from unlined cast iron pipe. Consumers served from cast iron water mains complained of a red water problem. Samples were collected from these sites to verify the presence of iron, and the iron concentration in these samples ranged from 0.4 to 1.9 mg/L.

Although the plant was designed with the ability to feed polyphosphate to control the red water problems, the appropriateness of this and other treatment chemicals was reviewed to address the anticipated requirements of the lead and copper rule. Zinc orthophosphate and silicate addition also were evaluated as treatment strategies. Calcium carbonate saturation was not considered a feasible or practical option, because it would involve the construction of additional feed systems to introduce both calcium and carbonate into the water.

Polyphosphates, although well-known for their ability to control red water problems by sequestering iron, were deemed inappropriate as a method to control lead- and copper-based corrosion. To control iron, polyphosphates generally require a pH in the 7.2 to 7.6 range, which is not optimal for control of lead or copper. Furthermore, polyphosphates have the ability to complex with lead and copper, potentially causing the concentration of these metals to increase (7). Zinc orthophosphate was considered for its ability to control lead by forming sparingly soluble lead orthophosphate films (14), but it is unable to provide a mechanism for control of iron corrosion. Also, there was concern that the zinc would be concentrated in the sludge generated by the community wastewater treatment facility. The use of sodium silicate reportedly has been a common strategy for low-hardness waters and has been favored for its potential to form a surficial coating on piping systems (15). In addition, silicate has a large capacity to disperse iron colloids, thus masking the red water problems (16). Several utilities in Maine with low alkalinity (<15 mg/L as $CaCO_3$) and low hardness (<5 mg/L as $CaCO_3$) have reported that sodium silicate was extremely effective in eliminating red water complaints. An advantage of silicates over polyphosphates is the pH range in

which each inhibitor is effective for control of red water problems. Polyphosphates can sequester iron at a pH generally <7.5, whereas silicates are effective in controlling red water problems at a higher pH (>8). The higher pH that can be used with silicate treatment is also more appropriate for controlling the dissolution of lead and copper. A well-known advantage associated with sodium silicate is that it does not contain zinc. Based on these considerations and system constraints, sodium silicate was recommended for full-scale performance testing.

With assistance from an engineering firm, the YWD designed a water quality monitoring program to track metal concentrations in response to the addition of sodium silicate over an extended period of time (18 months). Twelve sampling sites were identified throughout the distribution system to account for spatial variations in water quality. All sampling sites were cold water faucets located within buildings. First- and second-draw samples were collected from all 12 sites on the same day every 2 months. The first- and second-draw samples were analyzed for lead, copper, iron, calcium, and silica. A third sample was collected immediately after the second and analyzed for pH and alkalinity. The monitoring data collected over the course of 1991 are discussed in the following sections.

5.3.2 Findings

- The finished water produced from the YWD filtration plant without the application of sodium silicate has low alkalinity (8 to 10 mg/L as $CaCO_3$), moderately high pH (8.3 to 8.8), low turbidity (<0.10 NTU), low color (<10 CU) and is very soft (Ca <1 mg/L; Fe <0.05 mg/L). The water was corrosive toward lead and iron, as it produced an average lead level of 83 ± 145 µg/L in first-draw samples and iron levels in the range of 0.33 ± 0.55 mg/L from first- and second-draw samples. The finished water was less corrosive toward copper; the average copper level from first-draw samples was 0.15 ± 0.13 mg/L.

- Periods of 2 to 3 years might be required before the impacts of silicate addition can be determined, due to annual cycles in temperature and flow rate.

- The low buffering capacity of the plant water and variations in the coagulation process resulted in large pH fluctuations in the water exiting the filters. Sodium silicate fed into the filtered water served essentially two functions: to adjust the pH and to add silica to the finished water. As a result, it was extremely difficult for the operator to maintain a constant finished water pH and silica dosage.

- The alkalinity and pH were significantly lower at dead ends of the distribution system, especially when the dead-end lines were unlined cast iron. These areas consistently had lower silica concentrations and higher concentrations of corrosion products.

- Lead levels averaged 83 ± 145 µg/L during the initial sampling event when sodium hydroxide was being applied to finish the water during December and the first week of January 1991. After feeding sodium silicate in lieu of sodium hydroxide, the average lead levels in first-draw samples decreased and stabilized to 26 ± 22 µg/L during the period of May to December 1991.

- Red water complaints received by the YWD when sodium hydroxide was being fed were eliminated completely with the application of sodium silicate. Iron concentrations in the samples collected throughout the distribution system ranged from 0.10 to 1.9 mg/L before silicate treatment, and from 0.10 to 1.37 mg/L after treatment. It is likely, therefore, that silicate was sequestering iron.

- Iron concentrations showed only a slight reduction over time in response to treatment with silicate.

- Copper levels in the first-draw samples before application of silicate were relatively low, averaging 0.15 ± 0.13 mg/L and ranging from 0.06 to 0.48 mg/L. Application of sodium silicate reduced these levels slightly.

- Silica concentrations decreased as the water passed through the distribution system, suggesting that silica was coating the surface of pipes. Also, the average silica concentration in the first-draw samples was lower during each sampling event than the average silica concentration in the second-draw samples, suggesting that forms of dissolved silica were coating the internal surfaces of plumbing.

- With the average maintenance silica dosage of 11 mg/L used in this evaluation (startup period excluded), the chemical cost to the YWD is $8.12 per million liters.

5.3.3 Recommendations

- If silicates are used to control corrosion in soft, low-alkalinity waters, careful consideration must be given to the design of feed systems to ensure that a constant dosage of silica is provided. Therefore, it might be necessary in certain situations to adjust pH separately by the addition of another chemical, such as potassium or sodium hydroxide.

- In water with low alkalinity (<10 mg/L as $CaCO_3$), the use of silicates in conjunction with carbonate (alkalinity increase) adjustment should be investigated. Alkalinity could be supplied by silicates as long as the pH is raised into the 9.0 to 10.0 range. Increasing the alkalinity would minimize the pH reductions that occurred at the ends of the system.

- Studies should be conducted under controlled conditions to determine relationships among hardness, DIC, pH, existing films, silica dosage, and effectiveness of treatment.

- Full-scale water quality monitoring programs aimed at determining the effectiveness of silicate addition should be performed over a period of several years.

- When silicates are used as a means of corrosion control, pH, alkalinity, and silica levels should be monitored at the extremities of the distribution system.

5.3.4 Methodology

5.3.4.1 Description of the Facilities

The source of water for the YWD is a shallow (<10 m) pond. The facilities that process the water are an intake facility at the shore of the pond and a filtration facility. Water flows by gravity from the intake facility to the filtration facility. Although the intake facility contains equipment to permit addition of chlorine and potassium permanganate, these chemicals are not routinely added.

Water entering the filtration facility is injected with aluminum sulfate and sodium hydroxide for coagulation. After being coagulated, the water enters an upflow clarifier, consisting of plastic media retained by a stainless steel screen. The media retain a portion of the coagulated material, and the remaining residual particulate matter is retained on a mixed-media filter. Water exiting the mixed-media filter is chlorinated for disinfection before it enters a 300,000-gallon contact basin/clearwell. The pH of the disinfected water exiting the clearwell is raised to between 8.3 and 8.8, prior to the addition of ammonia gas, to maximize the formation potential of monochloramine. When the trial application of sodium silicate was initiated, it was fed through the sodium hydroxide feed system.

The distribution system consists of approximately 40 percent unlined cast iron pipe and 60 percent cement-lined cast and ductile iron pipe. The unlined cast iron pipe is approximately 50 to 100 years old. There are no known lead service lines or asbestos-cement pipe in the system. York is a coastal tourist community with the population served by the YWD ranging from 5,000 in the winter to approximately 10,000 in the summer. The large population fluctuation causes the average daily flow rate to range from approximately 1.3 mgd in the winter to 3 mgd in the summer.

5.3.4.2 Study Objective

The objective of the evaluation was to determine the effectiveness of sodium silicate in controlling iron, lead, and copper corrosion in the YWD's distribution system and within residential home plumbing systems. Effectiveness, in this case, means noticeable reductions in the concentrations of the referenced corrosion products over a period of 18 months. This report covers data collected over the first 12 months of monitoring.

5.3.4.3 Treatment Scheme

The sodium silicate solution used in the evaluation was Type N® (PQ Corporation, Philadelphia, PA), which has a silica (SiO_2) to sodium oxide (Na_2O) ratio of 3.22:1. It was selected because it was the least expensive available silicate solution in the region and because it has a relatively high SiO_2:Na_2O ratio.

The silicate dosages used in this evaluation were based on recommendations from the manufacturer and on information available in the literature (15,17). The goal was to follow the present practice of applying silica to control corrosion in water distribution systems. Over the first 2 months of the monitoring program, a silica dosage of 16 to 20 mg/L as SiO_2 was used. For the remainder of the monitoring program, the silica dosage was lowered to 8 to 12 mg/L as SiO_2.

5.3.4.4 Monitoring Program Design

The main objective of the monitoring program was to generate sufficient data to determine the effectiveness of sodium silicate in reducing levels of principal corrosion products, including lead, copper, and iron. Another goal was to gain an understanding of the potential mechanism of silicate corrosion inhibition (e.g., surficial coating) by monitoring silica concentrations throughout the distribution system. To meet these objectives effectively, a monitoring program was designed to track pH, alkalinity, calcium, lead, copper, and iron levels at 12 points throughout the distribution system over an 18-month period. Sampling events consisted of collecting three samples from each monitoring location on the same day.

Because water system personnel could gain regular entrance to only a limited number of buildings, a survey was conducted to identify and select individual homeowners to participate in the monitoring program. The selection of sites was based on the ability of the participating residents to understand and perform the prescribed sampling procedures effectively for the period of the monitoring program. In addition, the locations were apportioned throughout the distribution system, covering both the center and the ends of the distribution system (Figure 5-15). An extensive materials survey to identify specific sampling locations based on sources of lead and copper was not performed prior to the monitoring program.

In York, annual cycles in water flow through the distribution system and in temperature represent important temporal variations. It was necessary, therefore, to monitor water quality changes over a period of 18 months. Sampling was conducted every 2 months to account for changes in flow and temperature.

5.3.4.5 Sampling and Analytical Procedures

Sampling Procedures. First-draw and second-draw samples were collected from taps from 12 buildings throughout the distribution system (Figure 5-15). First-draw samples were collected after the water was allowed to stand motionless for 6 to 12 hours. Second-draw samples were collected after the tap had been flushed for a period of 5 minutes. The first- and second-draw samples were collected in 250 mL bottles, and each was analyzed for lead, copper, iron, calcium, and silica. A third 250-mL sample was collected immediately after the second-draw sample and was analyzed for pH and alkalinity. The three samples were collected on the same day from each of the 12 sites to relate metal concentrations to the referenced water quality parameters.

pH and Alkalinity. Samples for pH and alkalinity were measured in the laboratory within 24 hours of the time of collection. The pH was measured with an ORION SA250 pH meter. The meter was calibrated with pH buffer standards at pH 4, 7, and 10. The meter was recalibrated at the end of a group of analyses to check for instrumental drift. Alkalinity was determined by EPA (1983) Method No. 310.1 using 0.02 N H_2SO_4.

Lead, Iron, Calcium, and Copper. Upon arrival at the laboratory, samples for lead were acidified to pH <2 with concentrated nitric acid. Lead samples were analyzed on a Perkin

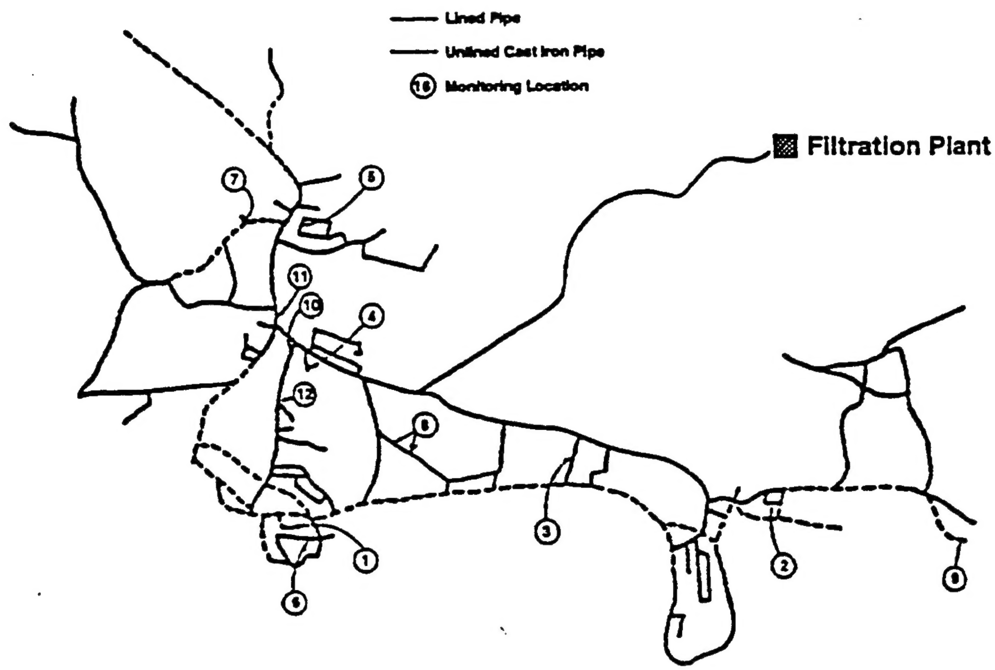


Figure 5-15. Map of the York Water District distribution system.

Elmer 5100 PC Atomic Absorption Graphite Furnace according to Standard Methods (1989) No. 3113 B. Samples for iron, calcium, and copper were analyzed on a Perkin Elmer Model No. 460 Flame Atomic Absorption Spectrophotometer, according to Standard Methods No. 3500 B. Field spikes and blanks were performed during each analysis to determine the accuracy of the method.

Silica. Silica analyses were conducted using Inductively Coupled Plasma (ICP) according to EPA (1983) Method No. 200.7.

Data Analysis. In the case of small sets of data, including outliers can result in a bias in the calculated mean. Therefore, sets of lead data from every sampling event were subjected to the Dixon Test to eliminate outliers.

5.3.5 *Results and Discussion*

The data collected for the evaluation of silicates are presented in the following two sections. First, treatment plant operating data over the 12-month period are discussed. Second, the results of the distribution system monitoring program are presented.

5.3.5.1 Plant Operating Data

Finished Water Quality Data. Table 5-2 summarizes the average annual finished water characteristics at the YWD filtration facility during the monitoring period. In general, the water is corrosive toward lead and iron due to its low alkalinity. With the exception of temperature, the finished water quality parameters do not vary significantly on a weekly or annual basis.

Table 5-2. Average Finished Water Quality Summary

Parameter	Mean	Standard Deviation
pH	8.5	±0.29
Alkalinity (mg/L as $CaCO_3$)	8.0	±1.65
Turbidity (NTU)	0.06	±0.01
Temperature (°C)	13.0	±3.0
Iron (mg/L)	0.03	±0.01
Manganese (mg/L)	0.06	±0.02
Aluminum (mg/L)	0.05	±0.04

Temperature. Temperature can have a pronounced effect on the rate of corrosion. In general, as the temperature increases, so does the corrosion rate of most materials. As illustrated in Figure 5-16a, the temperature in the finished water increased from 4°C during the winter to 24°C in the summer months. Therefore, the rate of corrosion due to temperature effects would be highest in the summer months.

Flow Rate. The average velocity of the water carried through a distribution system should increase, in general, as plant flow rate (output) increases. Velocity is an important physical factor that affects the rate of corrosion. Slow velocities within a distribution system cause water to be stagnant; often a marked decrease or increase in pH is observed. Velocity, as it relates to inhibitor-based corrosion control, is important in sustaining a passivating film on a pipe surface. As velocity increases, so does the rate at which a given mass of inhibitor comes in contact with a given unit surface area of pipe.

The quantity of water produced varied significantly from winter to summer (Figure 5-16b), due to seasonal population patterns. This variation had a tendency to cause stagnant areas during the winter months, which resulted in lower pH values at dead-end monitoring locations.

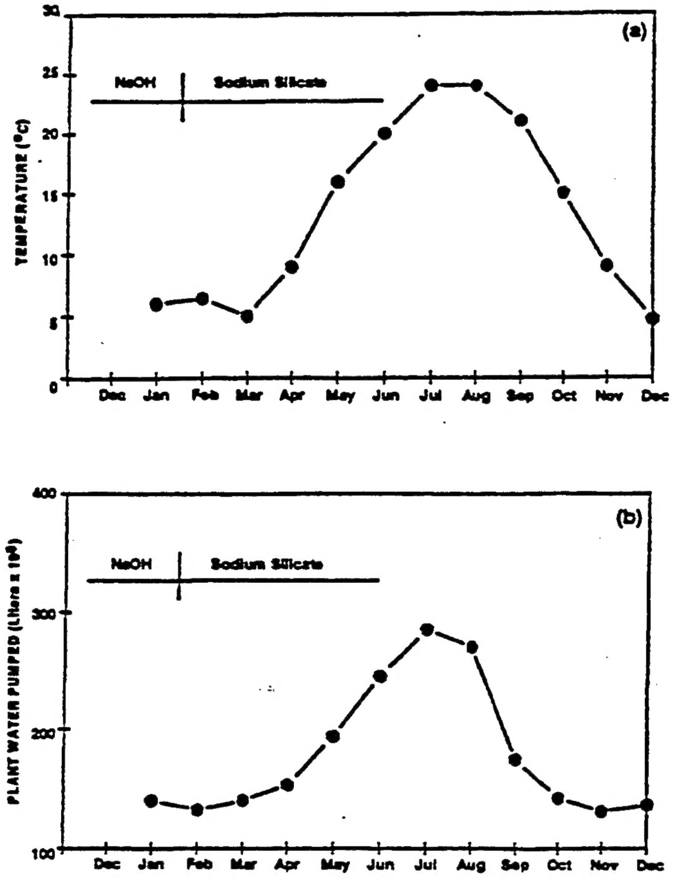


Figure 5-16. Temperature of the filtration plant finished water (a) and monthly water production (b).

Silica Dosage. The monthly average silica dosage and raw water silica concentrations over the course of a 12-month monitoring period are presented in Figure 5-17. The average silica dosages were determined by dividing the total volume of silica

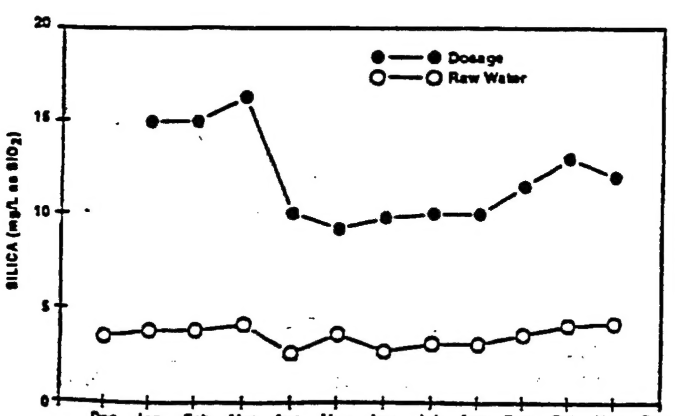


Figure 5-17. Average monthly silica dosages and raw water silica concentrations.

applied by the volume of finished water pumped. The silica dosages used in this evaluation (9 to 16 mg/L) were similar to dosages (12 to 20 mg/L) at a nearby utility with similar water quality conditions.

After reviewing the distribution system data in August, it was noted that the pH at remote points in the distribution system was low (<7.2). To raise the pH at these locations, the feed rate of sodium silicate was increased in September and October. As a result, the silica dosage increased (Figure 5-17) over the same time period. The sodium silicate solution, therefore, was performing two functions: to raise the pH of, and to add silica to, the plant finished water. The operating data suggest that the feasibility of feeding a more alkaline sodium silicate solution (lower SiO_2:Na_2O ratio) or accomplishing pH adjustment separately with another chemical, such as sodium or potassium hydroxide, should be investigated.

5.3.5.2 Distribution System Monitoring Data

pH. During the period when the finished water was adjusted with sodium hydroxide, prior to application of sodium silicate, the average pH from the monitoring points was 8.34 ± 0.26. When the average startup dosage of approximately 16 to 20 mg/L as SiO_2 was being administered, the pH from the sites averaged 8.38 ± 0.14. After the initial startup dosage was lowered to a maintenance dosage of 10 mg/L as SiO_2 during late March, the pH dropped to an average of 7.75 ± 0.10 for the remainder of the monitoring program (Figure 5-18).

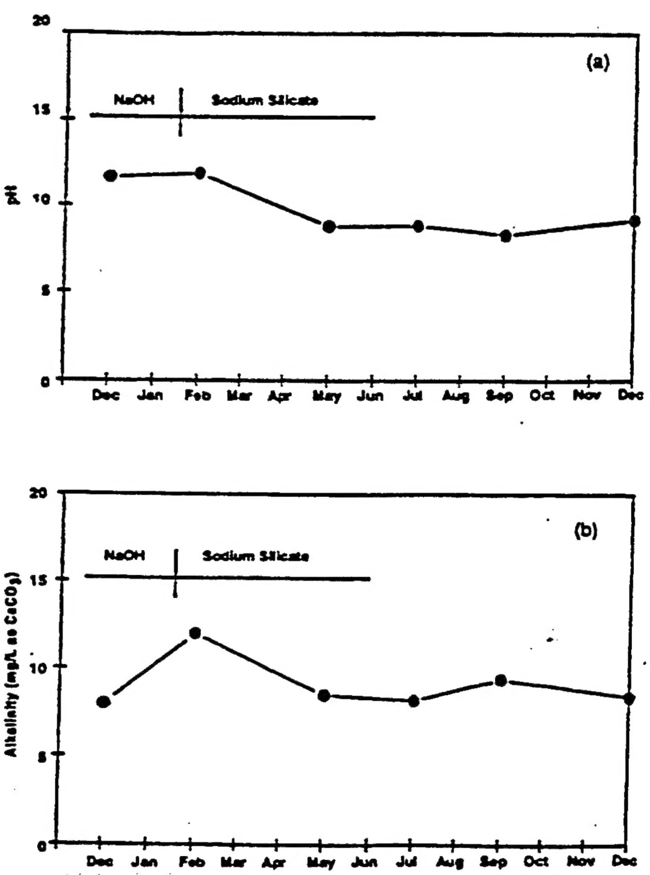


Figure 5-18. Average pH (a) and alkalinity (b) from the distribution sampling events.

At the dead ends of the system, the pH (7.52 ± 0.38; n = 3) was lower than the pH (8.17 ± 0.05; n = 8) at central points within the distribution system. Lower pH values observed are likely due to the release of metals such as iron, and subsequent hydroxide-ion uptake, which frequently occur in stagnant areas. The lower pH values are generally consistent with lower silica concentrations found in the same regions (see the following discussion on silica).

Alkalinity. The alkalinity typically ranged from approximately 5 mg/L as $CaCO_3$ at dead-end locations to 10 mg/L at most other points within the system. The average alkalinity remained relatively constant throughout the monitoring period, with the exception of a slight rise during February when the startup dosage of silica was being administered (Figure 5-18b). The increase in alkalinity was probably due to the presence of the anionic silica species, H_3SiO_4.

Silica. From the distribution system monitoring data, it can be seen that the silica concentrations in the center of the system were higher (17.8 ± 0.53 mg/L as SiO_2) than at the ends of the system (16.0 ± 1.2 mg/L) (Figure 5-19a). These data suggest that silica was being adsorbed onto pipe surfaces as the water moved through the system. Silica has the ability to adsorb onto metal-oxide surfaces (18,19). Potential evidence of this type of adsorption was observed in this study as the average silica concentration was lower (15.6 ± 1.5 mg/L; n = 3) at sampling sites located on unlined cast iron mains than at sites located on other types of pipe (17.5 ± 0.71; n = 9) (Figure 5-19a).

The calculated means of the first- and second-draw samples were compared; they displayed evidence of silica adsorption onto the surfaces of home plumbing systems (Figure 5-19b). Although these data suggest adsorption of silica was occurring, it cannot be confirmed without X-ray diffraction analyses.

Lead. Figure 5-20 shows the variation in lead concentration of first-draw samples over the monitoring period. Prior to application of sodium silicate, the lead levels ranged from 6 to 488 µg/L and averaged 84 ± 145 µg/L. Over the period of May through December, when the lead levels were relatively stable, the lead concentrations ranged from 5 to 166 µg/L and averaged 26 ± 22 µg/L (Figure 5-20a). These lead levels are relatively high, considering that 11 of the 12 buildings were constructed before 1981. The other building was constructed in 1990 and, as a result, contained pipes with lead-free solder. Since the first-draw sample volume was 250 mL, it is likely that the major source of lead is from brass fittings.

The average lead concentrations were consistently lower during the time when the sodium silicate was being fed. When

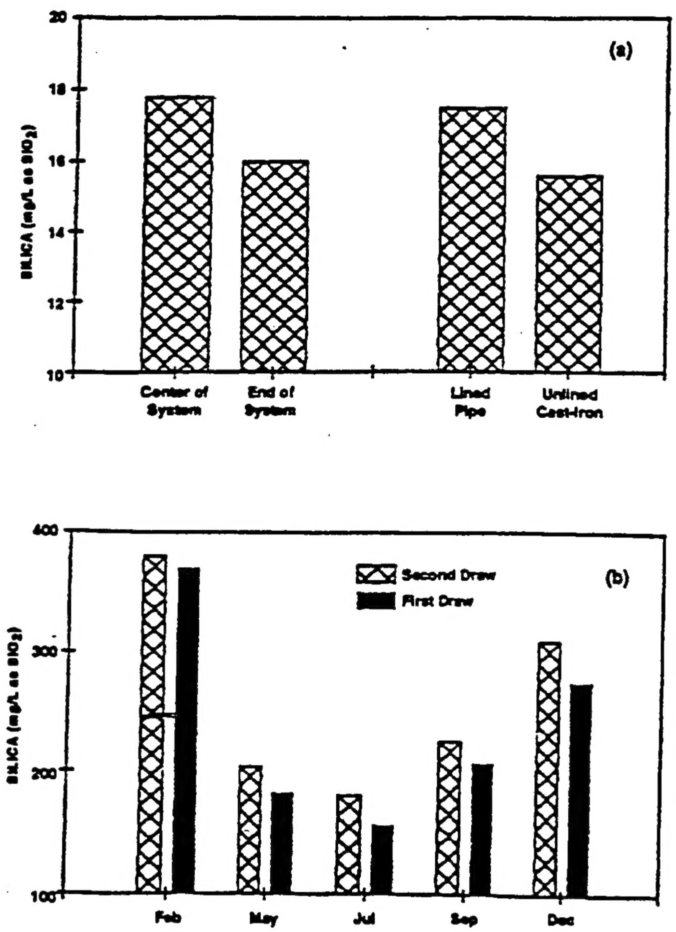


Figure 5-19. Silica concentrations from selected sites within the distribution system (a) and in first- and second-draw samples (b).

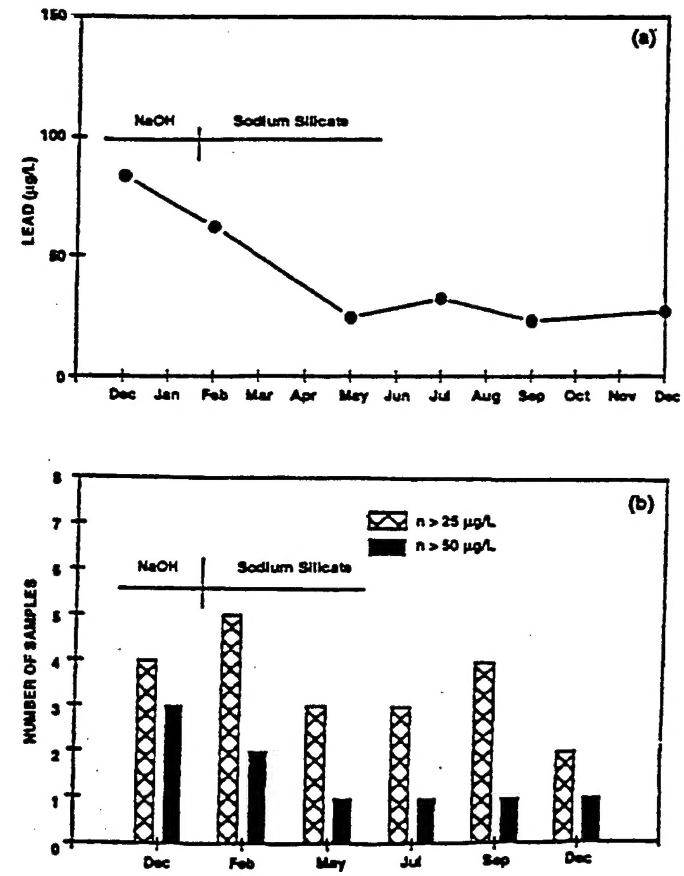


Figure 5-20. Average lead concentrations in the first-draw samples (a) and the number of samples exceeding specified concentrations in first-draw samples (b).

the number of samples exceeding >50 µg/L as lead and >25 µg/L as lead (Figure 5-20b) were compared before and after treatment, however, only a slight improvement was observed with the addition of sodium silicate. Second-draw samples, collected after flushing for a minimum of 3 minutes, were typically below the detection limit.

The highest lead concentrations were consistently found in samples collected at monitoring points on dead-end unlined cast iron mains, probably because of the lower pH values witnessed at these locations. Typically, the pH at these locations ranged from 6.6 to 7.2 compared to other sampling locations, where the pH was 7.6 to 8.5.

In general, some sites showed a consistent reduction in lead concentration; at other sites, the concentrations either remained relatively constant or increased. This result is to be expected since the source of lead (e.g., dezincification of brass, or dissolution of lead-tin solder) and types of films present will vary significantly depending on the specific location of the site. In particular, the dezincification of brass fittings, which was probably the major source of lead at most of the sites, can respond erratically to silicate treatment (20).

Iron. As shown in Figure 5-21, the iron concentration over time, after silicate addition, gradually decreased, and then increased, probably in response to low flow rates during the following fall and winter months. Each point on the figure represents the average iron concentration of 12 first-draw and 12 second-draw samples.

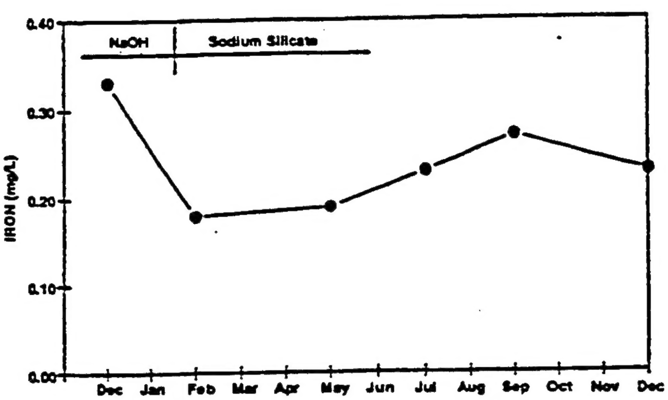


Figure 5-21. Average iron concentrations in the first- and second-draw samples.

During the last 6 months of 1990, the York Water District received approximately 15 red water complaints. Silicate treatment eliminated these complaints over the 12-month trial application. Iron concentrations ranged from <0.10 to 1.87 mg/L before treatment, and <0.10 to 1.37 mg/L after treatment; therefore, it is likely that the particulate iron was being sequestered by dissolved silica. The ability of sodium silicate to sequester oxidized forms of iron in soft, low-alkalinity water has been well documented (16).

Copper. Average first-draw copper concentrations from the six sampling events were especially low (Figure 5-22), as has been observed in other corrosion monitoring programs under similar water quality conditions (21). A possible reason for the low copper levels is that the first-draw sample volume was 250 mL; as a result, a large portion of the sample volume was contained within brass fittings and was not in contact with copper pipe.

The copper levels decreased during the initial sampling events but later increased during the winter (Figure 5-22). The increase was primarily due to a drop in pH at two monitoring stations located on dead ends. At dead-end monitoring stations located on unlined iron pipe, the copper concentration averaged 0.39 ± 0.04 mg/L, and at all other locations averaged 0.05 ± 0.02 mg/L. When the average copper concentrations are determined excluding dead-end monitoring points, there appears to be a slight reduction in copper levels from the application of silicate over time (Figure 5-22).

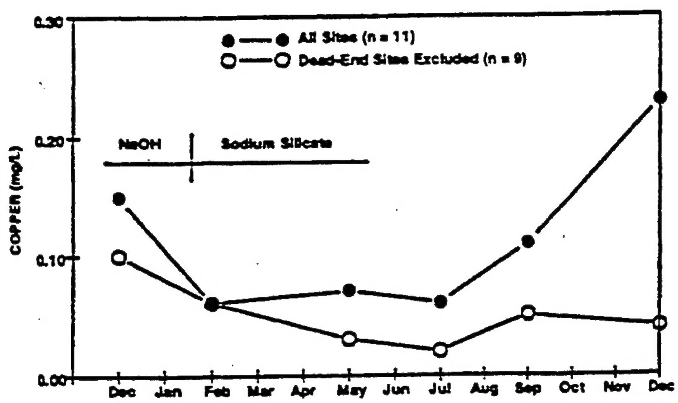


Figure 5-22. Average copper concentrations in the first-draw samples.

5.3.5.3 Treatment Costs

Given the average maintenance silica dosage of 11 mg/L administered between April and December, the cost of sodium silicate is $8.12 per million liters. This figure is based on bulk deliveries (≥15,142 L) of Type N® liquid sodium silicate and a bulk chemical cost of $21.30/100 kg ($73.70/100 kg as SiO_2).